PHYSICO-CHEMICAL EVOLUTION OF THE SAMBHAR LAKE SYSTEM, RAJASTHAN

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CERTIFICATE

Certified that the work presented in this thesis entitled **"PHYSICO-CHEMICAL EVOLUTION OF THE SAMBHAR LAKE SYSTEM, RAJASTHAN"** has been carried out by **Sri Saroj Kumar Panda** (Roll. No. 9510337) under my supervision and has not been submitted elsewhere for a degree.

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(SAROJ KUMAR PANDA)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

PLATES **PAGE No.**

ABSTRACT

The Sambhar lake, spreading over three districts, namely Jaipur, Ajmer and Nagaur of Rajasthan forms the eastern fringe of the Great Indian desert and is bounded by the neotectonically active Aravalli range. The region around this lake has varying thickness of alluvial and aeolian sand, kankar, calcrete and silcrete deposited on an uneven basement of Banded gneissic complex in the form of sand plain. An attempt has been made to study the geomorphological/neotectonic details of the area and to classify the region in various zones on the basis of neotectonism of the area. On the basis of sedimentology and clay mineralogy the source and occurrence of salt in Sambhar lake brine has been explored.

The digital processing of IRS LISS2 data has enabled the delineation of various cover units and geological structures, by enhancing the subtle tonal variations. Different image processing techniques such as false colour compositing, contrast stretching, edge detection , band ratioing and principal component analysis have been used to enhance the lithological and geomorphological features and their effect on the associated features like vegetation and soil. Several tectonic features have been identified with the help of geomorphologic units like drainage pattern, paleochannels, etc. and the region has been classified in terms of four tectonic blocks.

Using grain size and clay mineral analysis of sediments in the lake and comparing their characteristic properties with rock attributes of the surrounding Aravalli hills and the various parameters of the surrounding alluvial and aeolian plain, an attempt has been made to describe the source and occurrence of salt in Sambhar.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The first scientific study of lake, in about 1869, dealt mainly with the physico-chemical relations of lake Geneva, Switzerland. Since then, a variety of aspects related to lakes have been looked into. However, very little attention has centered on the geological aspects of lakes. All lakes are transitory in the geologic record because the very nature of the lake basin, a topographic low completely surrounded by higher areas, insures its inevitable destruction. Thus, many lake basins, often during the short life span of a man, pass through a recognisable cycle of destruction, from lake to pond, marsh, swamp or to dry land (Reeves, 1968).

The chemical composition of any lake water will ultimately depend on those elements and compounds in solution, suspension, and/or those accumulating along lake bottom, most of which come secondarily to the lakes by runoff. Other substances are produced by chemical reactions between different elements and/or compounds or as by organic activities (Eugster and Hardie, 1978).

Saline lakes are hydrologically closed basins which form in areas where evaporation exceeds precipitation (inflow). The total inflow is however is sufficient enough to maintain a standing body of water. Chemically, saline lakes are rich in Cl^-, Mg^{2+}, Na^+, K^+ and SO_4^{2-} ions which yield, in equilibrium in a saturated solution, only five solid

phases i,e. carbonates, sulfates, chlorides, borates and nitrates (Reeves, 1968). Beadle (1974) discussed the possible criteria to distinguish fresh water from saline waters and has chosen the boundary at about $5^{0}/_{00}$ dissolved solids, based principally on biological tolerance (Eugster and Hardie, 1978). Saline lakes may contain a variety of salt-tolerance plants from blue-green algea to sedges.

Remnant of pluvial lakes occupy closed basins in arid regions characterised by internal drainage. In such climatic regions the rivers, if present, never reach the sea. These are termed *endorheic* areas because they are under-drained by streams. The realm of desert limnology, by definition, coincides with regions where closed basins are found (Cole, 1979). Sambhar, Didwana and some other lakes of Rajasthan are characterised by endorheic drainage, with neglisible depth, containing only quaternary deposits (Biswas, Chattopadhaya and Sinha, 1982).

Saline lakes differ from fresh water lakes in two respects: (a) they continually experience a change in chemical composition and (b) there is a continuous increase in concentration of various salts in lake water, mainly due to a high evaporation rate. However, the increase in concentration of salt in a closed basin is not infinite. As water flows into the dry lake basin, perhaps with the first rain of the late summer or early fall, it carries the available salts in the catchment rocks and also dissolves the surface salts of the lake provided they have not been removed by deflation (Reeves, 1968). Even so , this is the time when the waters of the closed basins are the freshest. As precipitation declines, generally after the early spring rains , evaporation becomes greater than the inflow after which then starts the inevitable process of concentration of the salts in solution.

1.2 THE SAMBHAR LAKE AND ITS SURROUNDINGS

Spreading over three districts of Rajasthan, namely Jaipur, Ajmer and Nagaur, Sambhar is the largest inland saline lake of India covering approximately 225 sq. km. of area. Located in a gap of the Aravalli range, about 80 km. west of the pink city, the Sambhar lake is a hollow in a vast stretch of almost flat sand body. The present study is centered around the Sambhar lake (Fig 1.1) falling between latitude $26^0 52'$N-$27^0 02'$N and longitude $74^0 54'$-$75^0 14'$E covered in four Survey of India toposheets nos. $45\frac{I}{16}$, $45\frac{M}{4}$, $45\frac{J}{13}$ and $45\ \frac{N}{1}$. Sambhar is a shallow lake, reaching only about 3m at its deepest (Gopal & Sharma, 1994), with an average depth not exceeding 0.61 m. The maximum length of the lake basin is 22.5 km, while the width ranges from 3.2 km. to 11.2 km. The lake bed (360 m above sea level) is almost flat, with a slope of less than 10 cm per km. (Gopal & Sharma, 1994).

Climatically, the study area is situated over a transitional area with arid climate at the west and semiarid climatic zone towards the east of it. The total climatic factor of the area is governed mainly by monsoon and the physiography of the area , i.e. the Aravalli range. The southwest monsoon that originates in the western part of the Indian Ocean as the South east trade wind, is drawn north of the equator by a low pressure area over north-west India. As it crosses peninsular India, part of it swings north and then west over the Ganges plain, to lose the last of its moisture on the eastern slope of the Aravalli range. The average annual precipitation over this region (the study area) is 550 mm to 650 mm

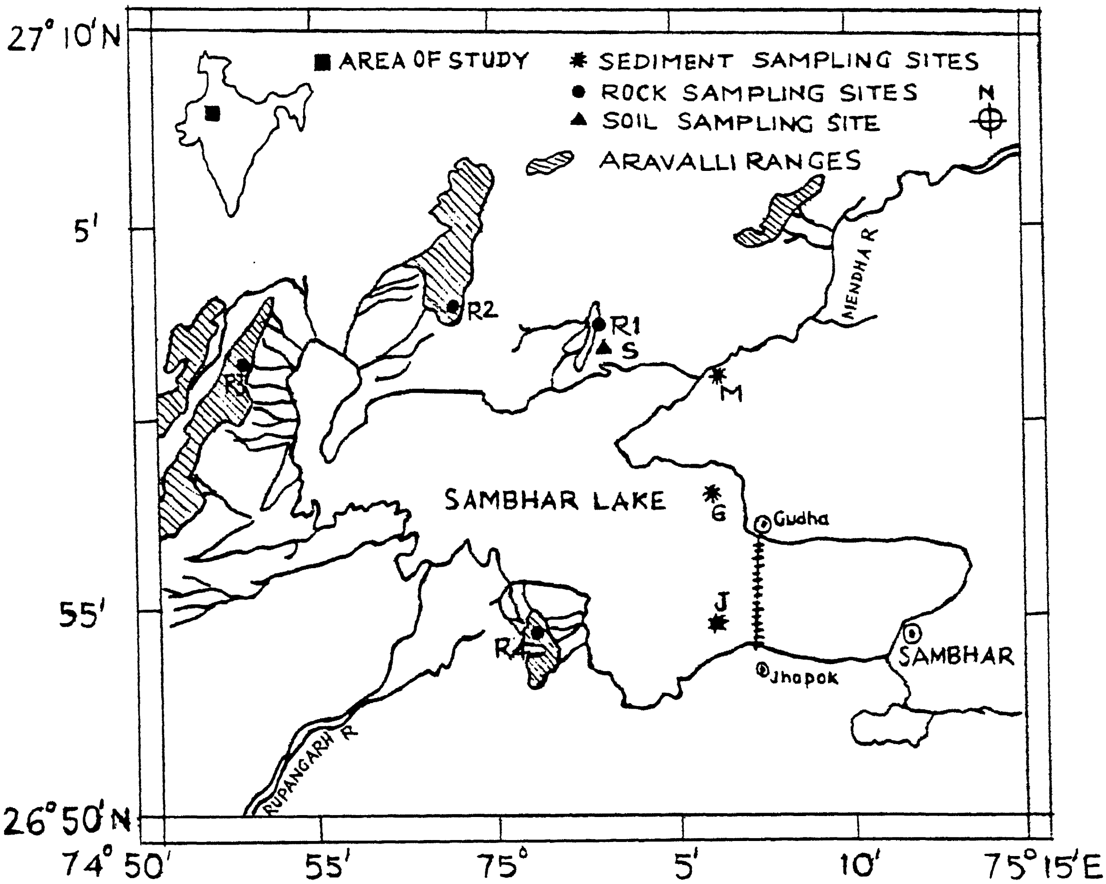


Fig. 1.1 Location map showing study area and sampling sites

and sometimes up to 800 mm. Another cause of low annual precipitation around this area is the relatively warm dry, anticyclone air that overlies the near surface air of the southwest monsoon (Pramanik & Ramanathan, 1952). This absorbs any moist air that rises along Aravalli range and results in the dissipation of any cloud and decrease the likely load of rain over this region. The southwest monsoon is though replaced on the autumn by light winds of northeast monsoon, but having had a continental route before reaching this area. The annual rainfall intensity as estimated by the meteorological department is 17.5 mm (Sharma, 1990). The average annual temperature of this region is 23^0C, the maximum being 45^0C. All these climate data nevertheless, suggest that the study area belongs to a semi arid region.

Countless effort is needed to prepare a proper note elaborating the importance of the study area. This area is equally important for scientific research work and economy of the country. Within the scientific community the geographers are turned on by this typical piece of transitional climatic zone sandwiched between arid and semiarid climatic zones. The Sambhar lake has drawn considerable attention from the ecologists as a natural laboratory to study the ecological diversity. It has the distinction of a "wetland of international importance" under Ramsar convention (1971). The problem of algal growth in the salt pans and reservoirs of the Sambhar lake is providing a tool for interdisciplinary study like biogeochemistry. The geological interest in to Sambhar lake has been strongly foccussed on the origin of hypersalinity in lake water.

The commercial utilisation of natural resources i.e. salt of Sambhar lake marks the industrial importance of the area. The Sambhar lake produces over 2 million tons of salt

per annum. In a major attempt to revive the Sambhar Salt Limited the Rajasthan govt. recently opened a large part of the lake for private organisations for a better exploitation of the salt resources. The adverse impact of industrial growth in the area on the delicate ecological system of the lake has also been a matter of extensive debate among the ecologist and the environmentalists.

1.3 REVIEW OF EARLIER WORK DONE :

A good number of research papers exist on the origin of hyper salinity in the Sambhar lake. A number of theories exist to explain the origin of salt in Sambhar lake, but non of them are satisfactory and there is still a lack of consensus among the research workers. Nevertheless, the existing theories on the chemical evolution of Sambhar lake have helped in adopting an integrated approach for the present study.

The earliest study on the salinity problem in Sambhar lake dates back to 1909 when Holland & Christie floated the wind borne theory, arguing the possibility of wind transportation of salt from the Rann of Cutch. But, the physiographic setting i.e. the lake bed at 360 m above mean sea level, and the wind mechanism of the area does not fit to their theory. Godebole (1952) postulated the sea water origin theory citing that in the geological past the Tethys sea extended up to the Aravallis and the valley now occupied by Sambhar lake was, at one time, a part of the ocean. The lake is thus a remnant of the sea. After the retreat of the Tethys sea, the lake got silted up and dried, leaving the accumulated salt in its sediments. Recently, Ramesh et al. (1993) have refuted the marine origin on the basis of limited isotopic analysis of water from Didwana, Sambhar and

Kuchaman lakes of Rajasthan. Biswas et al. (1987) have reviwed the existing theories and admitted that the environmental factors of extreme aridity and evaporation coupled with centripetal dranage may be the prime cause of input of salts into the lake. Bhatacharya et al. (1982) found a striking similarity in the chemical composition of the well brines and silt samples from Sambhar and Didwana, and thus, pointed towards the probability of a similar origin of salinity in the lake. According to them, the thick beds of halite, as recently discovered in Didwana, may also be the source of salinity in the Sambhar.

In a recent study, on the basis of Na/Cl and Cl/SO4 ratios along with isotopic data, Yadav (1995) discarded the earlier theories regarding the chemical evolution of the Sambhar lake water. After a thorough isotopic study of the Sambhar lake water, rain water and the ground water he concluded that the salt in the lake water is probably the result of evaporation of multiple component of source water viz. river water, ground water and atmospheric precipitation. In an attempt to fit his data to Eugster-Hardie model, he assumed that there is no interaction between solid formed and the residual water during the evaporation and also neglected the "ion-pairing" effects, and, thus, ended up with an anomalous high concentration of Ca and Mg ions which are much higher than the model predicted value. Then he suggested that the identification of authigenic minerals in solid phases such as the lake's sediments would provide information about the minerals controlling the brine evolution.

Sundaram and Pareek (1995) reported that the quaternary landforms in the northern and eastern proximity of the Sambhar lake are products of depositional, structural and erosional processes. The depositional landforms are made up of fluvial and

lacustrine and aeolian facies. The structural and erosional landforms are carved out of precambrian hard rocks. Of the two lacustrine facies the older is marked by the presence of saline deposits and the younger by saliferrous sediments. The depositional facies have evolved in a sequence which indicate slow variation in a predominantly arid climate. The presence of fluvial sediments forming the lake base contradicts the earlier observation which suggested an aeolian base for these lacustrine sediments.

Apart from the above geological studies, Gopal and Sharma (1994) have discussed about the biological diversity of the Sambhar lake. Large variety of phyto- and zoo-plankton, benthic invertebrates, fish and waterfowl existing in this wide range of salinity in the Sambhar lake. Particularly the seasonal behaviour of the blue-green algae is interesting and needs more attention so far as the brine evolution of the lake is concerned.

1.4 OBJECTIVES OF THE PRESENT WORK:

A review of the existing work on the Samhar lake strongly suggests that there is a need to take up a regional study of the Sambhar lake area. The studies so far have concentrated either on the lake catchment or on the lake itself. To understand the complexities of the physical and chemical evolution of the Sambhar lake, it was felt necessary to look at the geomorphological, sedimentological and sediment-mineralogical aspects simultaneously and to evaluate these data in the light of the available work on lake water chemistry and brine evolution. Keeping in view the above mentioned gap in the existing studies, the following objectives were envisaged for the present work:

1. Interpretation of physical evolution of the Sambhar lake through geomorphological investigation using remote sensing techniques followed by field investigation.

2. Interpretation of depositional environment and chemical evolution of the Sambhar lake through sedimentological and sediment-mineralogical studies.

1.5 PLAN OF WORK

Both inaccessibility and the vast expanse of the lake render it impracticable to sample water and soil from the entire lake bed. While the soft mud makes wading through the lake impossible, the shallow water impede boat movements. Thus, all the study conducted so far have, therefore, been biased towards sampling from few selective points mainly along the periphery of the lake. After understanding the pros and cons about the difficulties in accessing various parts of the lake, a plan was chalked out to orient the present work in a systematic way to achieve the objectives outlined above. The different work elements of the present study comprised of the following:

(i) A thorough literature survey was carried out and all published maps and data related to Sambhar lake and the surroundings were evaluated.

(ii) The first phase of field work was carried out in March, 1996 comprising of geomorphological investigations, collection of sediments and lake water samples and collection of relevant data from Sambhar Salt authorities.

(iii) Next, the geomorphological investigations through digital image processing of satellite data was taken up to understand the physical evolution of the Sambhar lake including the tectonic activities in the area.

(iv) The sedimentological characteristics and mineral constituents of the sediment samples from different localities (see fig. 1.1) were studied in the laboratory.

(v) The second phase of field work was carried out in October, 1996 for ground truth rectification of the remote sensing data analysis. Second set of sampling of sediments was also carried out followed by laboratory analysis.

(vi) Finally, the field and laboratory results were synthesized to work out a physico-chemical model for the evolution of the Sambhar lake.

1.6 ORGANISATION OF CHAPTERS

The present thesis has been divided into five chapters. Chapter 1 includes a brief discussion on the saline lakes followed by a discussion on the available literature of the Sambhar lake, and the scope and objectives of the present study. Chapter 2 reviews the regional geology and geomorphology of the area. Chapter 3 includes the details of remote sensing techniques used for the interpretation of geomorphology and tectonic activities in the area in order to understand the physical evolution of the present day lake basin. Following this, the chapter 4 discusses in detail the procedure for sediment sampling and laboratory set up for sedimentological and clay mineralogy studies and the interpretation of the data obtained. In chapter 5 the entire work is summarised and major conclusions have been drawn.

CHAPTER 2

REVIEW OF GEOLOGY AND GEOMORPHOLOGY OF THE SAMBHAR LAKE REGION

2.1 INTRODUCTION

The Sambhar lake region falls on the mighty Aravalli mountain range which has received considerable attention of geoscientists since C. A. Hacket first wrote a geological paper on it about hundred years ago. Studies made on diverse lines began to converge together, since then, permitting a regional synthesis.

The Aravalli mountain range of Rajasthan and northern Gujarat comprises a number of fold belts of early and middle proterozoic age. These proterozoic fold belts, like other proterozoic fold belts of the world, evolved through the development of series of basins in which sediments and volcanics were laid down in several successive groups bounded by unconformities. Beginning around 250 million years back, the records of the proterozoic events in the Aravalli mountain range can be traced as late as c500 million years before present.

2.2 REGIONAL STRATIGRAPHY AND STRUCTURAL EVOLUTION

The stratigraphic units forming this great mountain range include several unconformity-bound metasedimentary and metavolcanic units deposited successively over an ancient basement of plutonic rocks and para-gneisses. As a cover unit, Heron (1935,

an ancient basement of plutonic rocks and para-gneisses. As a cover unit, Heron (1935, 1953) recognised the "Aravalli system" as the oldest formation overlying the Banded Gneissic Complex (Roy, 1988), and the Bundelkhand gneiss (renamed by Pascoe, 1950, as the Berach granite) with a profound unconformity (Sen 1988). The "Raialo series" and the "Delhi system" are the two other cover sequences recognised by many workers. Table 2.1 shows the stratigraphic succession of the Precambrian rocks of the Aravalli mountain range as recognised by Sen (1988).

Table 2.1: Lithostratigraphic framework of the Aravalli Mountain Range

MALANI VOLCANICS ERINPURA GRANITE MAFIC AND ULTRAMAFIC INTRUSSIVES IN THE DELHI FOLD BELT CHAMPANER GROUP SIROHI GROUP(?)	
DELHI SUPERGROUP	*AJABGARH GROUP* *ALWAR GROUP* *RAYANAHALA GROUP*
//UNCONFORMITY//	
ARAVALLI SUPERGROUP	*UPPER – ARAVALLI GROUP* *LOWER – ARAVALLI GROUP*
//UNCONFORMITY//	
MEWAR GNEISS	*PRE – ARAVALLI GRANITE GNEISSES, AMPHIBOLITES, METASEDIMENTS, AND GRANITIC ROCKS.*

(After Sen, 1988)

A close scrutiny of the published maps of the Geological Survey of India (Fig. 2.1) reveals that the major parts of the Sambhar lake region is covered with quaternary deposits which, henceforth, conceal the facts about the exact structural and stratigraphic features. Nevertheless, it has been recognised that most of the outcrops west to this region

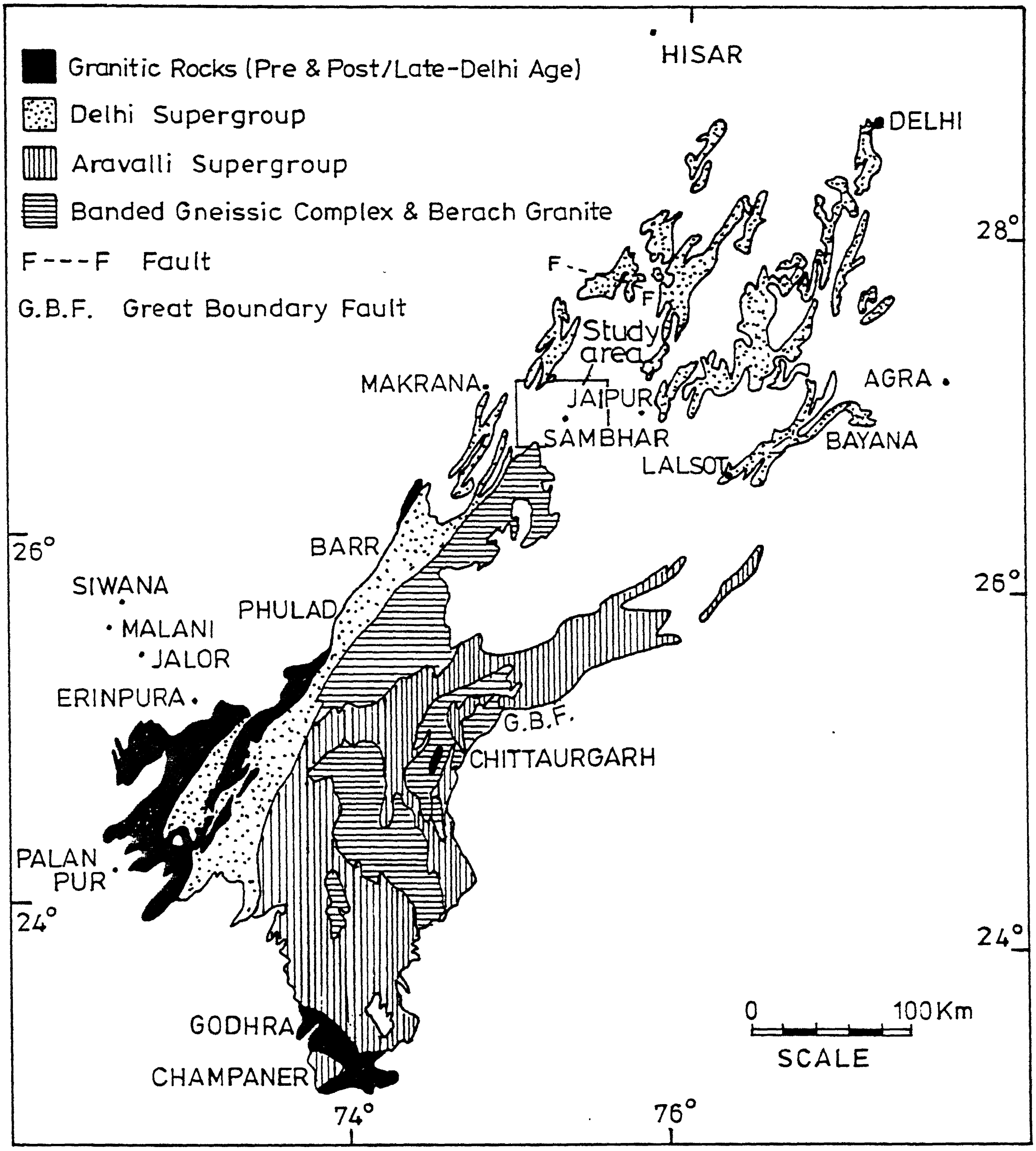


Fig. 2.1 Map showing the distribution of the Precambrian crystalline rocks in the Aravalli Mountain belt and its surrounding plains along with the study area (simplified after the published maps of the Geological Survey of India)

belong to the Delhi supergroup, and the BGC and the Berach granite lies towards the south of the area.

Zooming into the area of interest in the above discussed map (Fig. 2.1), it is clear that the Delhi supergroup, which constitutes the main edifice of the Aravalli range, occupies a narrow linear stretch in this part of the central Rajasthan. Sharma (1988) described the lithology of the Delhi supergroup rocks of this region as indicative of lower greenschist facies of regional metamorphism. The regional schistosity is considered synkinematic with folding on NE-SW axis and accompanied by low grade crystallisation of the metasediments (Basu, 1982; Gangopadhaya and Pyne, 1980; Singh, 1982).

The Banded Gneissic Complex (BGC) exposed towards the south of the study area is considered as underlying the supracrustal of the Aravalli and Delhis, and is characterised by polymetamorphic mineral assemblages. The mineral assemblages comprising the rocks of the region suggests high pressure conditions during which the upper stability of muscovite had been reached (Sharma, 1988). Geothermometric and geobarometric estimations by Sharma (1988) suggest a pressure of 5.5-6 kb and temperature range of 600^0-700^0C. The mineral assemblage comprising biotite-sillimanite- "melt", in which melt is coarse grained quartz, plagioclase and microcline (Sharma, 1988).

Three phases of folding have been recognised in the Delhi rocks (Mukhopadhaya and Dasgupta, 1978; Roday, 1979; Naha et al, 1984; Roy and Das, 1985). The DF1 and DF2 folding episodes appear temporally very close to each other (Banerjee and Mitra, 1977; Roy, 1988), both forming during the Delhi orogeny. Temporal reactions between the crystallisation and deformation suggest that the metamorphism of the Delhi

supergroup rocks of this region was broadly coeval with the two phases of deformations (DF1 and DF2), and the crystallisation outlasted the second deformation (Roy and Das, 1985).

This part of the Delhi basin is characterised by several fossil grabens, horsts and grabens (Singh, 1988). The neotectonically active "Sambhar-Jaipur-Dausa wrench fault" has been presumed to be a paleotransform fault separating the "north Delhi basin", which opened earlier from "south Delhi basin" opening at a later date (Roy, 1988).

2.3 GEOMORPHOLOGY, DRAINAGE AND SEDIMENTATION HISTORY

The Aravalli range, trending diagonally from north-east to south-west, opens out in a fan like fashion in Jaipur and Alwar districts. Described as the ridge and valley province, the Aravalli range in this part breached traversely to form a number of wind gaps including that near the Sambhar lake. An extensive pediplain truncates with the rocks belonging to the older sub divisions of the crust including the basement. The hill ranges are abruptly truncated both in the east and west, and show linear mountain fronts over long distances. The hill tops have preserved relict erosional surfaces at different levels with many of the hills showing first order topography, preserving anticlinal hills and synclinal valleys (Dassarma, 1988). The middle part of the pediplain is covered up with menacing aeolian sand shield and dunes of various morphological types. The drainage is essentially structurally controlled, showing preferred directions along NE-SW, E-W and NW-SE. A number of lakes including Sambhar lake occur in the eastern fringes of the wind gap and also across disorganised river courses.

Remnants of an earlier planation surface occur as narrow linear stretches of different elevations on hill tops and rise in stepped terraces from the adjoining plains (Dassarma, 1988). The surfaces are longitudinally bounded by NE-SW and N-S faults and fractures, fortified with scarps and truncated by E-W cross faults. Effect of post planation uplift and faulting are manifested in the abundance of spectacular hanging valleys all of which show three distinct steps in their rise (Roy and Sen, 1983).

In the present area effect of warping is discernible in the local segmented blocks bounded by longitudinal and cross faults (Sen and Sen, 1983). The anticlinal hills present in the area attains a maximum height at the middle and steadily decline in elevation both northward and southward by about 400 m till it is truncated by cross faults. A striking parallelism exists between the axes of warping and axes of DF3 folding in the area so much so that the maximum and the minimum elevation of the warped surface locally coincide with culminations and depressions of early fold axes where these are crossed by DF3 folding (Sen and Sen, 1983; Roy, 1983). Relevant in this context is the description of the DF3 formation as "broad warps" and "unaccompanied by internal deformation" (Roday, 1979), as "mild", "extremely local" and "non penetrative" (Roy, 1983) and as "broad open cross-folds" which generated "wider spaced fractures" (Sen and Sen, 1983). In the present case, the prevalence of N-S fractures and scarps parallel to the compression axis, the general rejuvenation of NW-SE striking faults fully bears out a N-S directed compression axis (Ghosh and Viswanatham, 1991). Faults trending E-W and parallel to the axes of warping are possibly of tensional origin.

The rejuvenated fault and fractures responsible for the segmentation of the erosional surface also control the overall drainage pattern of the area. The river Mendha flows straight along NE-SW stretches for major part of its course and shows N-S alignments particularly just before merging into the lake. All paleochannels of the Mendha river shows the initial dominance of NE-SW lineaments, and subsequent superposition of N-S through river capture. Differential uplift and tilting of N-S oriented blocks (Fig. 2.2) have been largely responsible for segmentation, ponding, disorganisation of rivers and formation of several saline lakes in the eastern fringe of the Aravalli range (Dassarma, 1988). Most of the river channels display contrasting morphologies in adjacent segments, locally grafting relict meanderal loops of Roopangarh river to insurgent straight headway of river Mendha. As free meandering suggests absence of tectonic control, the cumulative evidences of meandering and recurrent river captures along successive preferred directions suggest periodic impulses (Williams and Clarke, 1995)

Quaternary sedimentation is mainly restricted to the marginal fault troughs fringing the uplifted western and eastern margin of the Aravalli range. The formation of the troughs and their rapid filling during the quaternary period indicate normal faulting accompanying block uplift; the drowning of the sediment suggests continuation of movements (Blatt, 1980).

The deposition of linear alluvial valleys in successive parallel stretches suggests sedimentation in stepped graben in the Mendha valley (Fig. 2.2). The successive linear basins simulate stepped grabens formed by a series of antithetical faults heading towards the main fault (cf. De Sitter, 1956). The linear and parallel valleys in the Mendha basin

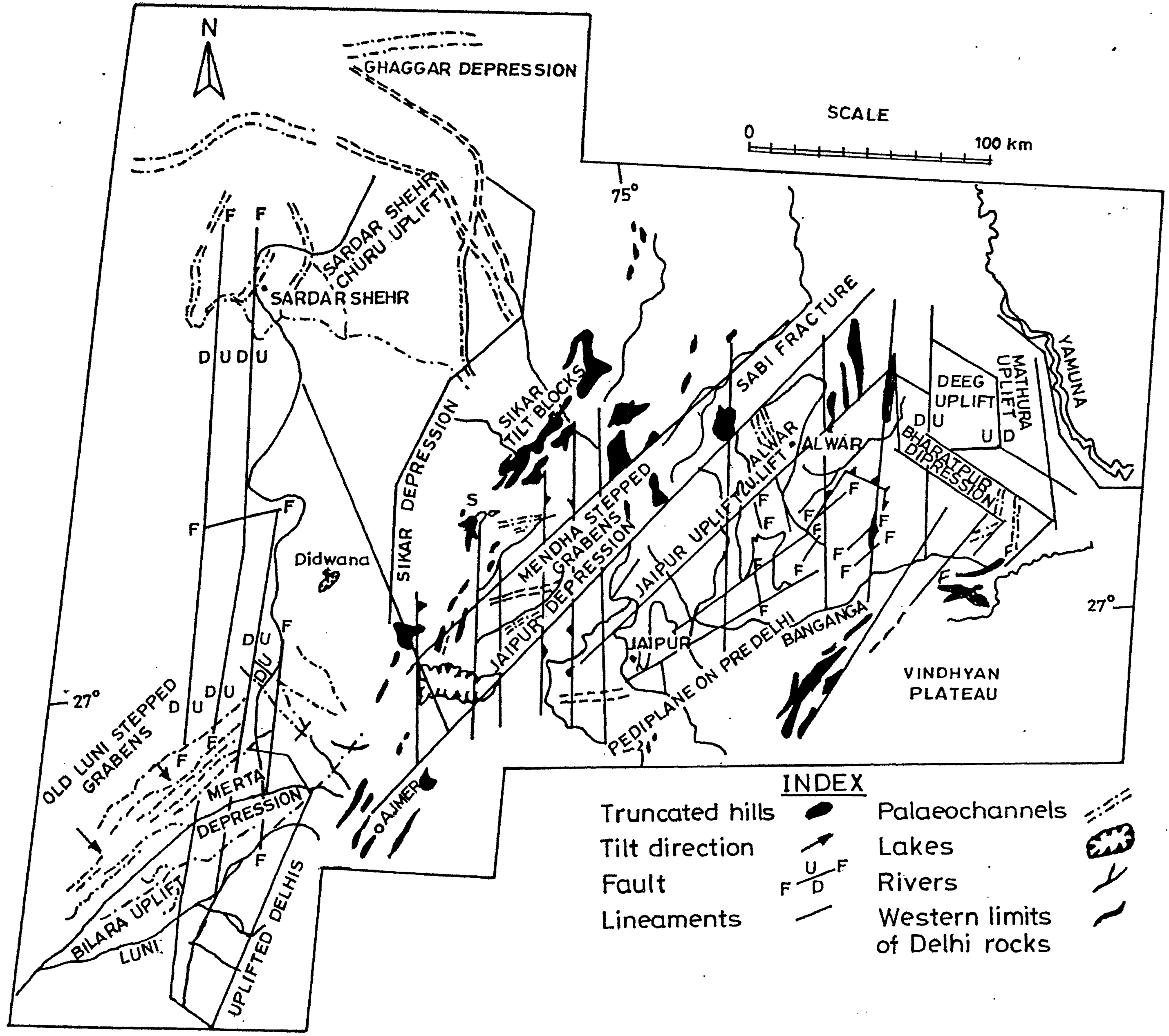


Fig. 2.2 Neotectonic map of northeastern Rajasthan: prepared from landsat imageries followed by field checks. (After Dassarma, 1988)

may indicate sedimentation either in Ridel shears formed oblique to the regional NE shear or in successive grabens formed by fault antithetic to the normal component of the original fault (Ghosh and Viswanatham, 1991).

2.4 NEOTECTONICS

A summary of the structural, geomorphological, pedological and stratigraphic evidences in support of neotectonic movements in north-east Rajasthan has been furnished by Dassarma (1988). Sen and Sen (1983) suggested a post neogene uplift of the Aravalli range as a horst which, according to them, took place through re-activation of older lineaments, principally the Great boundary fault in the east and the Sardarsahar fault in the west. The structural evidences comprise truncated hill fronts with fault scarps, in alluvium and silcretes, and post orogenic bending, shattering and dragging of ridges with rotational effects to form transverse wind gaps. The pedological features include relict silcrete and calcrete skins on topographic highs, and anomalous depths of oxidation in contiguous blocks on opposite sides of the NE-SW trending faults (Dassarma, 1988). Swarms of parallel structurallycontrolled paleochannels, lineament-controlled river captures, river diversions, ponding and formation of salt lakes across disorganised channels and anomalous terracing in adjacent rivers are the important geomorphological features suggesting neotectonic activity in the area. The stratigraphic evidence of neotectonism includes differential accumulation of sediments in contiguous blocks with local "drowned" quaternary topography.

Role of rotational movement was suggested for the formation of the conspicuous wind gaps, transverse to the Aravalli mountain range between Sambhar lake and Kantli

river where a series of NE-SW, NW-SE and N-S faults intersect each other (Dassarma, 1985). A comparison of lineaments indicated by Mendha stepped grabens suggests a relative clockwise relation of the crustal block east of the Aravalli orographic axis (Fig. 2.2). The rotational process has also pulled apart a series of marginal depressions in the eastern fringes of the gaps to form the Sambhar and some other smaller lakes with linear boundaries.

Anhert's work (1970) on the relationship of denudation, relief and uplift suggests that if the uplift is only isostatic, then the main relief of any terrain will probably be reduced to 10 per cent of its original value after 30 million years. Thus, assuming the Aravalli range as an absolutely stable region at least since Mesozoic, the present mean relief of 300m would imply a relief of 3,000 m in Oligocene and 30,000 m in Paleocene. Such high relief would suggest that the present topographic and geomorphic features of the Aravalli range to be interpreted as rejuvenated feature of late Tertiary or early Quaternary age.

A possible driving force for the post-orogeny movements could be during the late Pliocene early Pleistocene time when the continental crusts of the Indian and Eurasian plates became locked (Sen and Sen, 1983). The differential movement caused rotation of some of the blocks along reactivated faults, ripping open in the process linear depression to form Quaternary sedimentation basins and lakes. The absence of sediments earlier than Quaternary in all these depressions provides stratigraphic evidence for recent movements (Roy and Sen, 1983). The movements were perhaps impulsive as suggested by anomalous terracing and ephemeral meandering phases of paleochannels.

CHAPTER 3

GEOMORPHOLOGICAL INVESTIGATION AIDED BY REMOTE SENSING DATA

3.1 INTRODUCTION

Remote sensing by definition is the method of acquiring data about an object without any physical contact with the object itself. It has two facets: the technology of obtaining data through a device which is located at a distance from the object, and the analysis of the data for interpreting the physical attributes of the object, both these aspects being intimately inter-linked with each other (Gupta, 1991).

The fundamental principle of remote sensing is that, depending upon the physical and/or compositional attributes of the object certain intensity of light reflects within a particular range of electromagnetic spectrum (Fig. 3.1). Thus using information from one or more wavelength ranges it may be possible to differentiate between deferent type of objects and map their distribution on the ground.

Geomorphology deals with the study of landforms and landscapes, including their description, type and genesis. Landform is the end product resulting from the interaction of the natural surface agencies and the type of rock (Bloom, 1969). It depends on three main factors such as (a) climatic setting, including its variation in the past (b) lithology and structure, and (c) the time span involved.

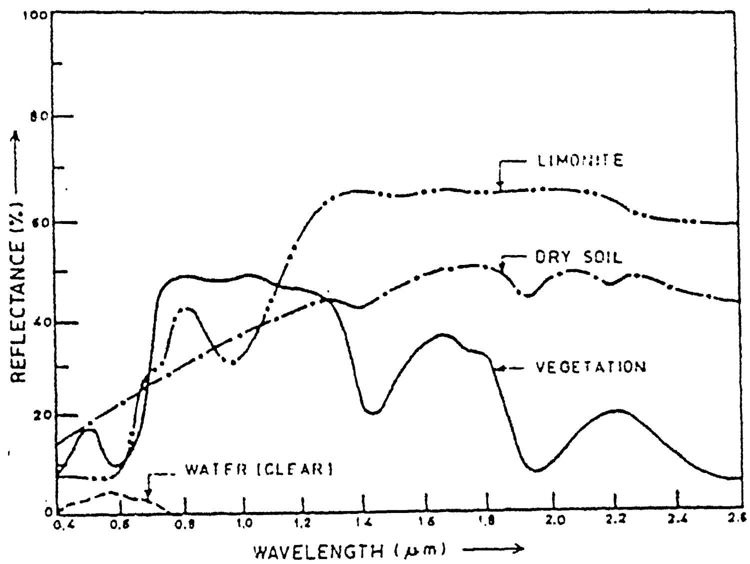


Fig. 3.1 Typical spectral reflectance curves for selected common natural objects— water, vegetation, soil and limonite

(source Gupta, 1991)

One of the widest application of remote sensing data has been in the field of geomorphology, because remotely sensed data products give direct information about the surface feature on the earth. Also landform features can be well studied in a regional scale using synoptic coverage provided by remotely sensed satellite data, rather than in the field.

3.2 DATA AVAILABLE AND METHODOLOGY

The digital remote sensing data of IRS-1B LISS2 used in the present work is provided by NRSA, Hyderabad. Linear Image Self Scanning (LISS) pay load of Indian remote sensing satellite IRS-1B consists of three solid state cameras: low resolution (72.5m) LISS1, and medium resolution (36.25m) LISS2A and LISS2B. LISS1 provides a swath of 148 km, while the composite swath of LISS2A and LISS2B is 145 km. IRS satellites are placed in a 904 Km polar sun-synchronous orbit with an orbit period of 103 minutes. The satellites return to their original orbit trace every 22 days enabling repeat collection of data over the same place and at the same local time. The detail specifications of the data used are listed in Table 3.1.

Table 3.1: Specification of the data used

Production identification code	: 96/568_01_1
Date of product generation	: 03/19/1996
Satellite	: IRS 1B
Sensor	: L2A
Path-Row	: 30-49
Sub-scene/SOI map sheet No.	: A1
Date of pass	: 21 Nov. 1995
Input scene centre latitude (degrees)	: 26.82112313
Input scene centre longitude (degrees)	: 75.173448
Inter pixel distance (meters)	: 36
Inter line distance (meters)	: 36
Band Interleaving Indicator	: BIL
Band Nos.	: 1 2 3 4
Record level of volume directory file	: 360 bytes
Record level of leader file	: 3960 bytes
Record level of imagery file	: 2520 bytes

LISS cameras observe radiance reflected from earth's surface in four bands of the following wavelength: 0.45 μm to 0.52μm (Band 1), 0.52 μm to 0.59 μm (Band 2), 0.62 μm to 0.68 μm (Band 3) and 0.77 μm to 0.86 μm (Band 4). Table 3.2 lists the major characteristics of IRS bands and their applications.

Table 3.2: IRS Spectral Bands and their principal applications

Band No.	Spectral range(μm)	Spectral location	Principal applications
1	0.45-0.52	Blue	Sensitive to sedimentation, deciduous/coniferous forest cover discrimination
2	0.52-0.59	Green	Green reflectance of healthy vegetation
3	0.62-0.68	Red	Sensitive to chlorophyll absorption by vegetation, differentiation of soil and geological boundary
4	0.77-0.86	NIR	Sensitive to green biomes and moisture in vegetation, land water contrast.

A micro processor based digitally controlled auto tracking frequency colour monitor (HC 3925 series) from Mitsubishi Electric Corporation was used to display the images from a MS-DOS with 486 DX main processor and 256 Kb kache memory. The main software used in this study was ERDAS and sometimes the help of another PC based software namely IDRISI was taken. ERDAS (Earth Resource Data Analysis System) is an efficient PC based GIS package developed by ERDAS Inc. Ltd. This package is widely used by various agencies round the globe for analysis of satellite data for geology, forestry, pedology, agriculture, environmental sciences, etc. This software contains various programs and algorithms to enhance the available satellite data. The multi-band

digital data of the Sambhar lake area were processed using standard image processing techniques. Various image transformations were applied to enhance the geomorphological features present in the study area which enabled to interpret the physical evolution of the Sambhar lake and its surrounding. The results obtained through image processing were verified through actual field visits. The details of the image processing techniques and their results are presented next.

3.3. DIGITAL IMAGE PROCESSING OF SATELLITE DATA OF SAMBHAR LAKE AREA

Digital image processing involves the manipulation and interpretation of digital images with the aid of a computer. The digital image is fed into a computer one pixel at a time. The computer is programmed to insert these data into an equation, or series of equations, and then store the result of the computation for each pixel. These results form a new digital image that may be displayed or recorded in pictorial format or may itself be further manipulated by additional programs. The possible forms of digital image manipulation are literally infinite (Lillesand and Kiefer, 1994). Image enhancement, one category of digital image processing, is the process of making an image more interpretable for a particular application. Enhancement can make important features of, raw, remotely sensed data more interpretable to the human eye. Enhancement techniques are often used to study and locate areas and objects on the ground and deriving useful information from images. The various enhancement techniques used in this present work include spectral enhancement, spatial enhancement, multi-band enhancement and principal component transformation.

3.3.1. Spectral Enhancement

Spectral enhancement deals with the individual values of the pixel in the image. The goal of spectral enhancement is to make certain features more visible in an imagery by bringing out the contrast. Depending upon the features to be extracted and the band in which they appear, spectral enhancements such as linear contrast stretching was applied to a particular band data.

Single band images were extracted from multiband data and displayed on monochrome plain after contrast stretching. Each band exaggerates certain features while suppressing others depending on the reflectance value of the surface cover. Band 3 being sensitive to chlorophyll highlights the vegetation as dark gray patches (Plate 3.1). It helps in differentiating soil types and delineating geological boundaries. In this band fresh and salt encrusted sand is represented by the brightest tone while old sand is represented by lighter shades of gray. Contrast stretched image of Band 4 (Plate 3.2) is elaborating the land water contrast, and green biomass and moisture being sensitive to this wave band appearing as distinct patches of lighter tone in the image. The manmade structures are delineated from their distinct pattern and contrasting tone with the surrounding in the band 3 (Plate 3.1) image. In band 1 image the fresh alluvial sediments are appearing as brightest tone while the aeolian and the old alluvial sediments are showing lighter tone.

3.3.2. Spatial Enhancement

Spatial enhancement technique emphasize or de-emphasize image data of various spatial frequencies, which is the difference between the highest and lowest values of a

contiguous set of pixels. Jensen (1986) defines it as " the number of changes in brightness values per unit distance for any particular part of an image". The process of averaging small sets of pixels across an image is called convolution filtering which is used to change the spatial frequency characteristics of an image (Jensen, 1986). For example, a Zero spatial frequency produces a flat image where every pixel has the same value; a Low spatial frequency is an image consisting of smoothly varying gray scale, and high spatial frequency results an image consisting of a checkerboard of black and white pixels.

The commonly used convolution kernel are high frequency kernel, zero-sum kernel and low frequency kernel, as given bellow:

$$\begin{matrix} -1 & -1 & -1 \\ -1 & 16 & -1 \\ -1 & -1 & -1 \end{matrix} \qquad \begin{matrix} -1 & -1 & -1 \\ 1 & -2 & 1 \\ 1 & 1 & 1 \end{matrix} \qquad \begin{matrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{matrix}$$

High frequency kernel   Zero-sum kernel   Low frequency kernel

In the present work, high frequency kernel and zero sum kernel were used. High frequency kernel serves as an edge enhancer, since they bring out the edges between homogeneous groups of pixels. Unlike edge detectors (such as zero sum kernels), they only highlight edges, they do not necessarily eliminate other features. While low frequency kernel simply averages the value of the pixels, causing them to be more homogeneous (homogeneity in low spatial frequency). The resulting image looks more smooth or more blurred. The filtered images of bands 1, 2 and 4 were loaded separately in planes 1, 2 and 3 respectively to make the colour composite.

The edge enhancing high frequency filter produced an image (Plate 3.3) which illustrates the geological and structural features as well as topography. The quartzite ridges of this area are very well identified as narrow linear patches of white colour which are accompanied by dark gray shades indicating foothills. The relief differences of different topographic features are indicated by the shades of white, brown and pink. The zero sum edge, on the other hand, produced an image which helps in demarcating the edges efficiently.

3.3.3. Multi-Band Enhancement

A peculiar aspect of remote sensing is that it provides data in multiple spectral bands which can be super-imposed over one another to deduce information not readily seen on a single image (Gupta, 1991). Radiometrically corrected IRS LISS2 data of bands 1, 2 and 4 were loaded at three different planes (1,2 and 3). Red was associated with band 4, green with band 2 and blue with band 1 to generate a False Colour Composite (FCC). The histogram obtained for each band image was stretched separately and superimposed (1:1 ratio).

The FCC (Plate 3.4) provides a regional view with respect to geology, topography, drainage and vegetation in different shades of colours. The shades of dark brown represent greatest height corresponding to quartzite and quartzoschist ridges and light brown colour represents sand dunes and sand mounds of different heights. Most of the drainage seen on the image are dry channels and are depicted by the shades of white and while the plaeo-channels having high moisture content and scanty vegetation

ıte 3.3 Spatially enhanced image of band 4,2,1 ng edge enhancing high frequency kernel

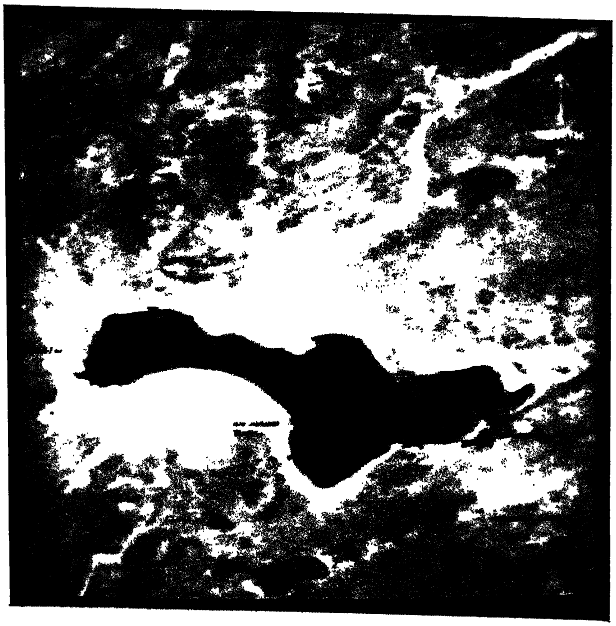


Plate 3.4 Multiband enhancement— standard FCC prepared by coding band 4,2 and 1 data on red, green and blue colour respectively

developed on it are depicted by ink blue shades. Apart from the main Sambhar lakes, a few smaller lakes are also seen which seem to be connected by one of the old channels. Thickly vegetated area are represented by different shades of red colour. The different part of lake are well depicted in this FCC as main lake body shows deep blue colour while the reservoir and the bittern part of the lake are showing green and black colours respectively.

The FCC shown in Plate 3.5 was obtained by coding band 4 with red, band 3 with green band 1 with blue shows a better contrast between different land covers. The Aravalli ridges are represented by narrow elongated zones of deep brown colour. While the alluvial fans developed on the footslopes are represented by lighter shades of brown (Plate 3.5). Drainage and salt encrusted sand are represented by brightest tone. Dark green colour represent vegetation while the lighter shades of green are representing aeolian sand and sand dunes of different altitude. Different parts of the lake viz. the main lake body, the reservoir and the bittern dumped eastern part are also well demarcated in the imagery (Plate 3.5).

Principal Component Transformation (PCT) is a technique designed to remove or reduce the redundancy in multispectral data. This transformation may be applied either as an enhancement operation prior to visual interpretation of the data or as a pre processing procedure prior to the automated classification of the data (Lillesand and Kiefer, 1994). If employed in the later context , the transformation generally increases the computational efficiency of the classification process because PCT may result in a reduction in the dimensionality of the original data set (Gupta, 1991).

Using PCT technique a new set of coordinate axes were fitted to the image data. The first new axis or component represents an orientation which shows maximum variance accounted for that axis. Subsequent components (axes) account for successively smaller portions of the remaining variance. The covariance matrix of the PCT is given in Table 3.3.

An enhanced colour composite (Plate 3.6) was produced by loading the images (PC1, PC2 and PC3) in planes 1, 2 and 3 respectively. The product of PCT (Plate 3.6) highlights the characteristic differences between fluvial and aeolian sedimentary units, and drainage of past and present origin. The Aravalli hills are represented by narrow linear patches of dark green colour and Lighter shades of green represents the Quaternary fluvial deposits of various generations while the aeolian deposits of various generations is represent by light pink (old) and white (younger). Past drainage and filled up depressions are represented by narrow linear patches of light greenish yellow colour. Present drainage is prominently represented by the narrow linear patches of blue colour. Salt encrusted alluvial sands spreading over the deltas and dried channels are represented by different shades of pink.

Table 3.3 : Covariance Matrix of the Principal Components

BAND	*1*	*2*	*3*	*4*
1	43.43	32.92	49.69	28.56
2	32.92	28.14	44.16	27.36
3	49.69	44.10	94.71	88.21
4	28.56	27.36	88.21	142.87

Plate 3.5 Multiband enhancement— FCC prepared by coding band 4,3 and 1 data on red, green and blue colour respectively

Plate 3.6 Principal Component Transformation (PCT) — enhanced colour composite by loading the images (PC1, PC2 and PC3) on planes red, green and blue respectively

Plate 3.7 Band ratioing— band ratioed image using $\dfrac{X4-X3}{X4+X3}$

Plate 3.8 Band ratioing— band ratioed image using $\dfrac{X1-X2}{X1+X2}$

3.3.4. Band Ratioing

Band ratioing is an extremely useful procedure for enhancing features on the multi spectral images. It is used to reduce the variable effects of illumination condition and topography (Gupta, 1991). The new digital image is constructed by computing ratio of DN values in two or more input images, pixel by pixel. The general concept can be formulated as:

$$DN_{new} = m\left(\frac{DN_A \pm K_1}{DN_B \pm K_2}\right) + n \quad \text{Where,}$$

DN_A= DN values in input image A

DN_B= DN values in input image B

K_1 and K_2= factors which take care of path radiance present in two input images, and

m and n= scaling factors for gray range

Image for complex ratio parameters including addition, subtraction, multiplication and double ratios etc. can be generated similarly. The resulting ratio image can again be contrast stretched or used as a component for other enhancements.

Ratioing is done mainly taking only band 4 and band 3 data as in band 4 vegetation has a lower radiance than soil and in band 3 the opposite is true. The mathematics used to delineate natural stream flow and vegetation patterns which align with geological structures is given as $\frac{X4 - X3}{X4 + X3}$ where X represents the DN values of that band.

This ratioed image after contrast stretching and enhancement (Plate 3.7) illustrates thickly vegetated area with white patches while the streams are represented by linear patches of gray shades.

To suppress the minute details of the area and to exaggerate the land, water and vegetation in a broad scale another mathematics was also used taking the band 1 and 2 data, which is given as $\frac{X1 - X2}{X1 + X2}$.

The resultant image (Plate 3.8) shows water and salt encrusted sand as brightest tone while the vegetation are represented with the dark patches. The aeolian sand plain is showing an intermediate tone. In this image the present day channel is well demarcated which helped in determining the drainage pattern and thus in preparing tectonic map.

3.3.5 Classification

Multispectral classification is the process of sorting pixels into a finite number of individual classes, categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that correspond to that criteria.

Depending upon the type of information to be extracted from original data, classes may be associated with known features on the ground or may simply represent area that "look different" to the computer. An example of a classified image is a land cover map, showing vegetation, bare land, pasture, urban areas, etc.

Pattern recognition is the science-and-art of finding meaningful patterns in data which can be extracted through classification. By spatially and spectrally enhancing an image, pattern recognition can be performed visually or through a computer system. The later case is more scientific.

The study area being a typical semi-arid region poses a serious problem in classifying the satellite data through known image processing techniques. The measurement of vegetation cover in this semi-arid region is complicated by variability in the soil reflectance as well as spectral interactions between the sparse plant canopies and the soil. This problem is well elaborated and discussed by Ray and Murray (1996) for desert vegetation. To minimise the problem reasonably two separate classification algorithms were used to enhance the classes in the lake and those in land (mainly soil) separately. One is the clustering algorithm and the other is the ISODATA algorithm. Though in both the cases the mapping of the vegetation as different class was not possible to its best extent, but it has solved the problem of enhancing the classes both in land and in lake separately.

In clustering algorithm, statistics are derived from the spectral characteristic of all pixels in an image and then, the pixels are sorted based on mathematical criteria. The statistical method of unsupervised training takes into account the homogeneity of neighbouring group of pixels, instead of considering individual pixels equally (Lillesand and Kiefer, 1994). The algorithm only uses 3×3 sets of contiguous pixels that have similar measurement vectors. Any other 3×3 windows of pixels are discarded. The assumption

behind the used algorithm is that contiguous, homogeneous pixels usually indicate a spatial pattern within the data (such as land cover type) that is worth classifying.

The output clustered image (Plate 3.9) represent the descrete hills of Aravalli range as dark green patches surrounded by alluvial fans showing blue patches. Still lighter blue patches represent sand dunes and mounds of different height. The pink patches which spread all over either of the river channels and their deltas along the lake shore represent moist salt encrusted sand having higher reflectivity. The red tints within this pink patches represent relatively higher altitude. The aeolian sand is represented with patches of lighter pink (old sand) and yellow patches (new sand and sand dunes). The pink patches outside either of the river channel and lake shore represent paleo-channels. The three major parts of the lake body is distinctly separated with brine reservoir being deep blue in colour while bittern is represented with the darkest tone. The main lake body shows intermediate shade of blue. The clusters of green patches all over the area except those representing linear trend of the Aravalli hills are representing vegetation.

ISODATA stands for " interactive self-organised data analysis technique". It is a "iterative" classification technique and in that way it repeatedly performs an entire classification and recalculate statistics. " Self organising" refers to the way in which it locates clusters with minimum user input (Lillesand and Kiefer, 1994). The ISODATA method is somewhat similar to the sequential method discussed above. They both use minimum spectral distance to assign a cluster for each candidate pixel. The major differences are that the ISODATA process begins with a specified number of arbitrary cluster means, and then it process repetitively, so that those arbitrary means will shift to

Plate 3.9 Classified image using statistical clustering of pixels of PCs

Plate 3.10 ISODATA classified image showing various classes in lake water

the means of the cluster in the data. Because the ISODATA method is iterative, it is not biased to the top of the data file, as are the one-pass clustering algorithms.

A image file is created, which gives results similar to using a minimum distance classifier on the signatures that are created. The image file (Plate 3.10) shows a number of classes inside the lake water. These classes probably representing different salinity level and/or difference in sediment dispersion pattern, as the gradient of the lake bottom does not suggest that these classes are because of the depth of the water column. The pink patches in the image (Plate 3.10) represents salt encrusted sands. The light gray patch rimming the lake is indicating mud. The two different classes in the lake water needs greater attention. However, this can be considered as due to cumulative effect of different physical and chemical conditions in different parts of the lake.

3.4 DATA ANALYSIS AND INTERPRETATION

Multispectral remote sensing data has shown tremendous potential for application in various branches of geology- geomorphology, structural geology, lithology, ground water and geo-environmental studies, etc. The interpretation of image data, whether enhanced or simple products, is carried out using elements of photorecognition- tone or colour, texture, shape, size and pattern; and geotechnical elements- landform, drainage, vegetation, land use and soil. The rock attributes (structure, lithology, etc.) and physical processes (climatic setting, weathering and erosional agencies) operating in a region over a time, govern the nature and appearance of landscape- relief, topography, vegetation, drainage, soil, etc. (Fig. 3.2).

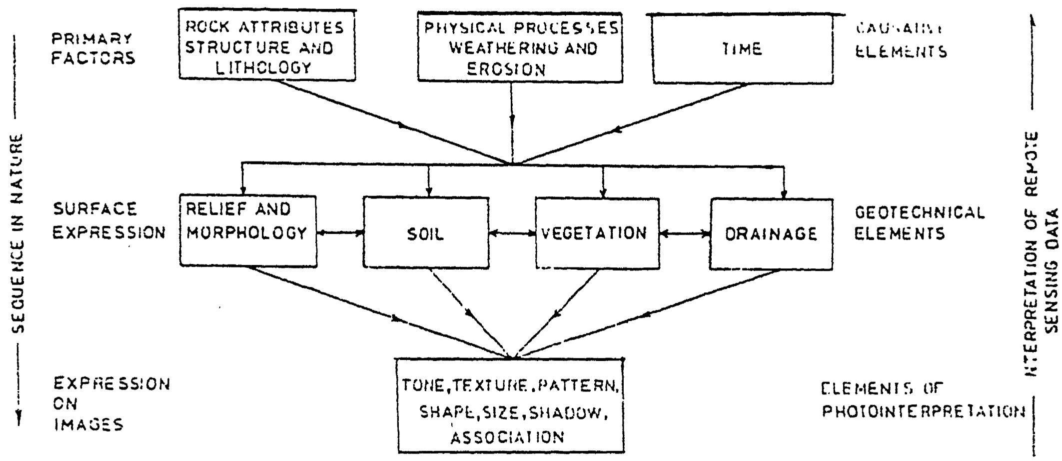


Fig. 3.2 Conceptual diagram showing various parameters with their sequence in nature

The study area is an classic example of manifestation of aeolian, fluvial and lacustrine processes and landforms. Of these wind action is certainly predominant while surface water processes assume importance during the monsoon period. The effect of lacustrine process is marginal as the lake is shallow in nature; maximum depth being slightly more than 1m during monsoon, and is practically devoid of any current and tidal action. Further the area shows numerous evidences of neotectonism. Using the digitally processed images, toposheets and followed by ground checks, thematic maps were prepared with respect to geomorphology, structure, lithology, etc. of the Sambhar lake area and its surroundings (Figs. 3.3 and 3.4). The geomorphological processes and the landforms related to these three different environments are discussed separately.

3.4.1 Fluvial Processes and Landforms

The fluvial action in the Sambhar lake catchment is performed by two major rivers of this locality namely, Mendha and Rupangarh, flowing from NNE and SSW direction respectively. As the flow of water in these two channel systems are not maintained throughout the year, a better terminology for these two inlet systems to the lake would be "Wadi". Many other small streams are debauching from the Aravalli hills and continuing their flow till their course is chocked up by their own load or by the migrating wind derived sand bodies or dunes. The entire drainage systems of this area is structurally controlled as suggested by their drainage patterns.

Amongst the two major wadis, the channel of the Mendha is wider than that of the Rupangarh. Again the channel of the Mendha is narrowing down towards the lake. The

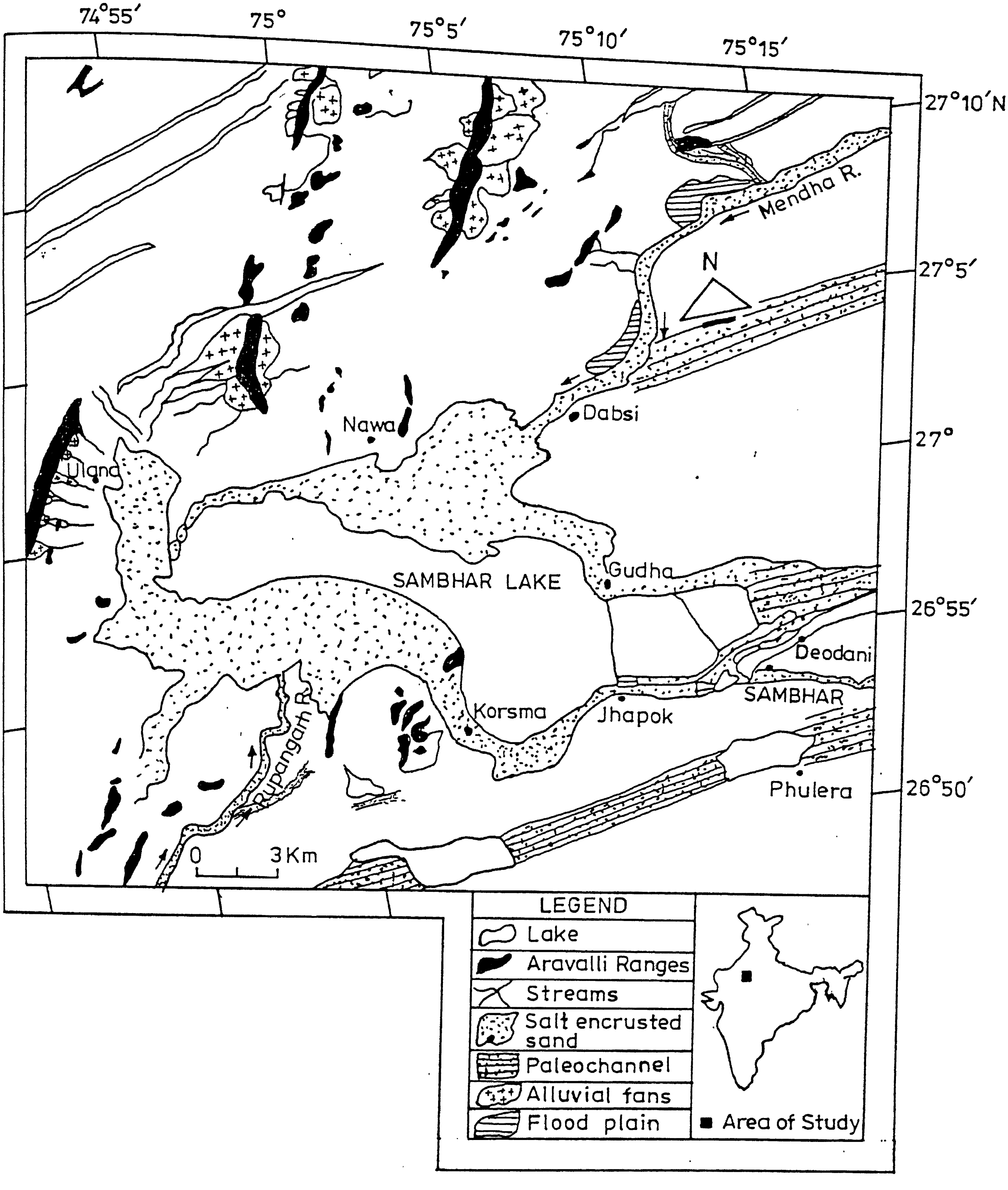


Fig. 3.3 Geomorphological map prepared from digitally processed satellite images aided by Toposheets and ground checks

Mendha is approaching the lake in a straight course from NE direction till its course is forced to follow a N-S alignment by the presence of a fault. The Mendha is maintaining a straight course throughout the area suggesting a strong structural control. Near the bridge (Plate 3.7 and 3.8) the channel of the Mendha is found to be chocked up by sand dunes of barchan type and the satellite image shows that the Mendha channel disappears into the ground here. But, the presence of deltaic deposits in northern shore of the lake suggest that immediately after rain the Mendha probably gets reactivated and then starts to flow following the rain. The damming of the water in its channel would cause the accumulation of water and then a flash flood removing all aeolian sands deposited along its course. The presence of flood plain deposits on the western bank of the river (Fig. 3.3) supports this hypothesis.

In contrast to the straight course of the Mendha, the Rupangarh has a cumulative expression of meandering and river capture prior to its final merge into the lake. This kind of drainage pattern suggests the neotectonic activity in periodic pulses (William and Clarke, 1995).

Both the rivers have a number of paleochannels suggesting lateral shifting of channels in the recent past (see Fig. 3.3). The general shifting pattern of the channels present towards the North of the lake is rotational, being rotated in the anticlockwise direction. But the channel of the Rupangarh which is present towards the south of the lake shows a general shifting towards NW direction. The differential channel migration pattern on either side of the lake suggests the presence of two separate tectonic blocks on either side of the Sambhar lake which are tilting and/or moving individually. This may be the

cause of the formation of the Sambhar lake basin. Apart from the above discussed paleochannels there are some paleochannels present in the southern and eastern side of the lake which do not seem to be related to either of the two major drainage systems of the area. These are showing almost E-W trend, and the one present parallel to the southern edge of the Sambhar lake has two small lakes within it's channel (Plate 3.4 and 3.5; Fig. 3.3).

Apart from the drainage systems of the area, the other fluvial landform present in this area are the coalescing alluvial fans (Plate 3.11). These are formed by the streams debauching from the Aravalli range from all the sides. The streams debauching from the Aravalli peaks nearer to the lake continue their flow into the lake thus feeding it with water and sediments directly from the hills. The coalescing alluvial fans are covering a huge area in the foothills. The small stream course are of swinging pattern on these alluvial fans as noticed in this satellite imagery.

3.4.2 Aeolian Processes and Landforms

Whatsoever their origin, the sand grains, in this region are transported over the surface by the wind, until the surface wind velocity is reduced sufficiently for them to come to rest. On a large scale, this is happening in the continental Sambhar basin and in other depressions present in the area and in the topographic traps formed by the Aravalli range (Plate 3.12). On a small scale, sand grains come to rest in the comparative protection of the lee side of the boulders and/or vegetation, or in the shelter of a river bank as seen in the field.

Plate 3.11 Standard FCC showing alluvial fans around Aravalli hills

Plate 3.12 Ground photograph showing alluvial fans and aeolian sand deposits near lake bed, Nawa

As considerable amount of sands are available, sand dunes are developed at many locations with deposition taking place mostly on the lee slopes of crescent or barchan dunes (Plate 3.13). As loose sands are readily transported, most major accumulations of sand dunes- the sand seas of this region- are occurring in depressions, as seen on the Sambhar basin and in the adjoining lowland areas surrounded by hills on both the sides (Plate 3.12).

Barchans sand dunes are seen on the Mendha river bed which suggests an interplay of aeolian and fluvial processes; wind is also rearranging the available alluvial sands on the river bed in dune forms (Plate 3.13). So far as the wind erosion is concerned, many faceted and polished blocks, and pedestal blocks were observed all along the Aravalli range during the field tour. The wind abrasion and attrition is producing large amount of sand from the nearby rock exposures.

3.4.3 Lacustrine Processes and Landforms

The Sambhar lake present in this region is the most important and extensive of the saline lakes of Rajasthan. It occupies a huge area of about 233 km^2 with its long axis aligned approximately in the East-West direction. The lake fills to a depth of over 1m during the rainy season but dries out completely during the summer months.

The lake interior is inaccessible due to the presence of swamps developed in the peripheral region, as observed during the field tour. The outermost part of the swamps dried up during the summer months and can be accessed. As the depth of the lake is not conducive for any kind of mode of transport in the water, the only possibility of collecting

samples is from the periphery of the lake. thus it is very difficult to study various aspects at the middle part of the lake.

The eastern part of the lake forms a reservoir for salt production and is detached from the main body through a dam connecting Jhapok and Gudha sites (Plate 3.14). Most researchers have collected lake water samples near the gate of the dam due to easy accessibility. A part of the reservoir is divided into no of kyars where the lake water is evaporated to achieve the required density level for salt production. The water samples from these kyars give a anomalously high concentration of salt. Also, a large population of algae are reported in the kyar. The biogeochemical activity in the kyar and brine reservoir are well reflected in the FCCs with a different colour expression. The mud excavated from the floor of the kyar i,e. "bittern" are dumped further eastern part of the lake and is well demarcated in the FCCs (Plate 3.4 and 3.5). The dried surface of the lake in the months of the summer shows polygonal cracking with salt mixed with clay filling the cracks.

A terrace is reported at the western periphery of the lake. Due to the shallow depths the tidal and current action are not manifested in the lake, however seasonal variation of water column is observed, as reported by the local people. Lake is mainly fed by Mendha, Rupangarh and other small streams. But, the ground water contribution to the lake can not be ruled out as there are number of "losing" streams present in the area., forming potential ground water recharge zones. Further, presence of fractures, faults and other lineaments would also encourage ground water recharge to enter into the lake. The lake deposits consist of grain size distribution of sands and clays carried by the rivers to the lake and those transported by the wind. The lake sediments suggest that they are

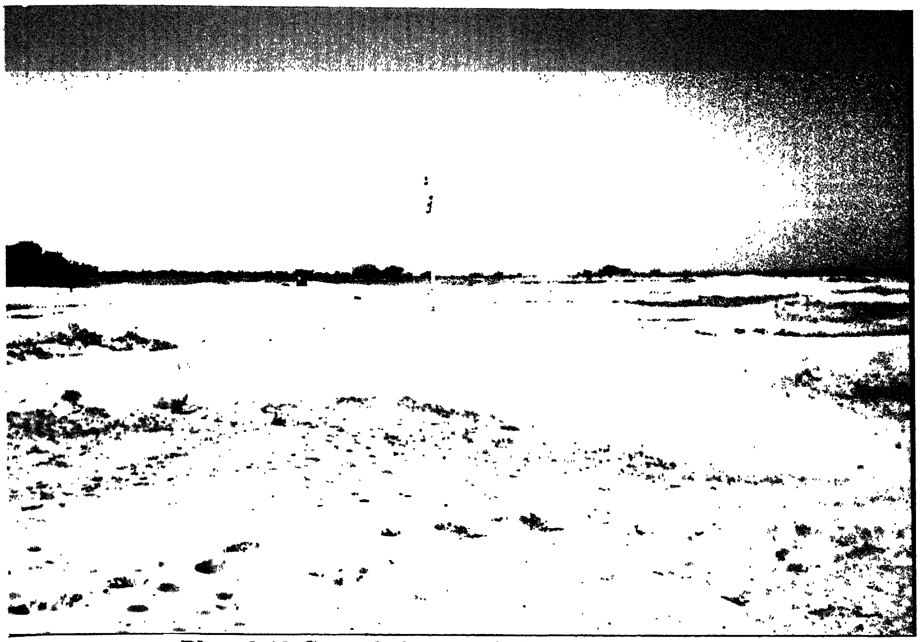


Plate 3.13 Ground photograph showing barchan type sand dunes developed on Mendha river channel

Plate 3.14 Standard FCC showing different parts of the Sambhar lake

derived from various sources and also transported with various modes (discussed later in chapter 4). The in-situ clay mineral formation in the lake sediment is inferred and an attempt has been made to elaborate the role of the organism in this clay formation (discussed later in chapter 4).

Gigantic sand mounds and dunes are reported at the SE fringe of the lake. These dunes seem to have been stabilised due to kankar formation at their bases (pedogenic?) and growth of vegetation. It has been inferred these sand were once the part of the lake sediment and in the later period excavated and transported through wind deflation. The high wind through the gap in the Aravalli from the west of the lake and the presence of the above discussed sand dunes and mounds on the eastern periphery of the lake strongly support this theory.

3.4.4 Geomorphology and Tectonics

The satellite imageries and field observations reveal a number of tectonic features present in the area which are manifested in the overall geomorphic expression of the area. The typical drainage pattern, off-setting of rivers, linear alignment of small lakes and disrupted Aravalli range are only some of the features strongly suggestive of tectonic activity in the area. A structural (tectonic) map (Fig. 3.4) has been prepared by visual interpretation of the band 4 image (Plate 3.2) and the directional filter product of band 3 and band 4 (Plate 3.3). Various structural units have been high lighted and the most possible directions of movements is shown in the map (Fig. 3.4). The visual interpretation and field observations suggest that the whole area can be divided into four tectonic blocks.

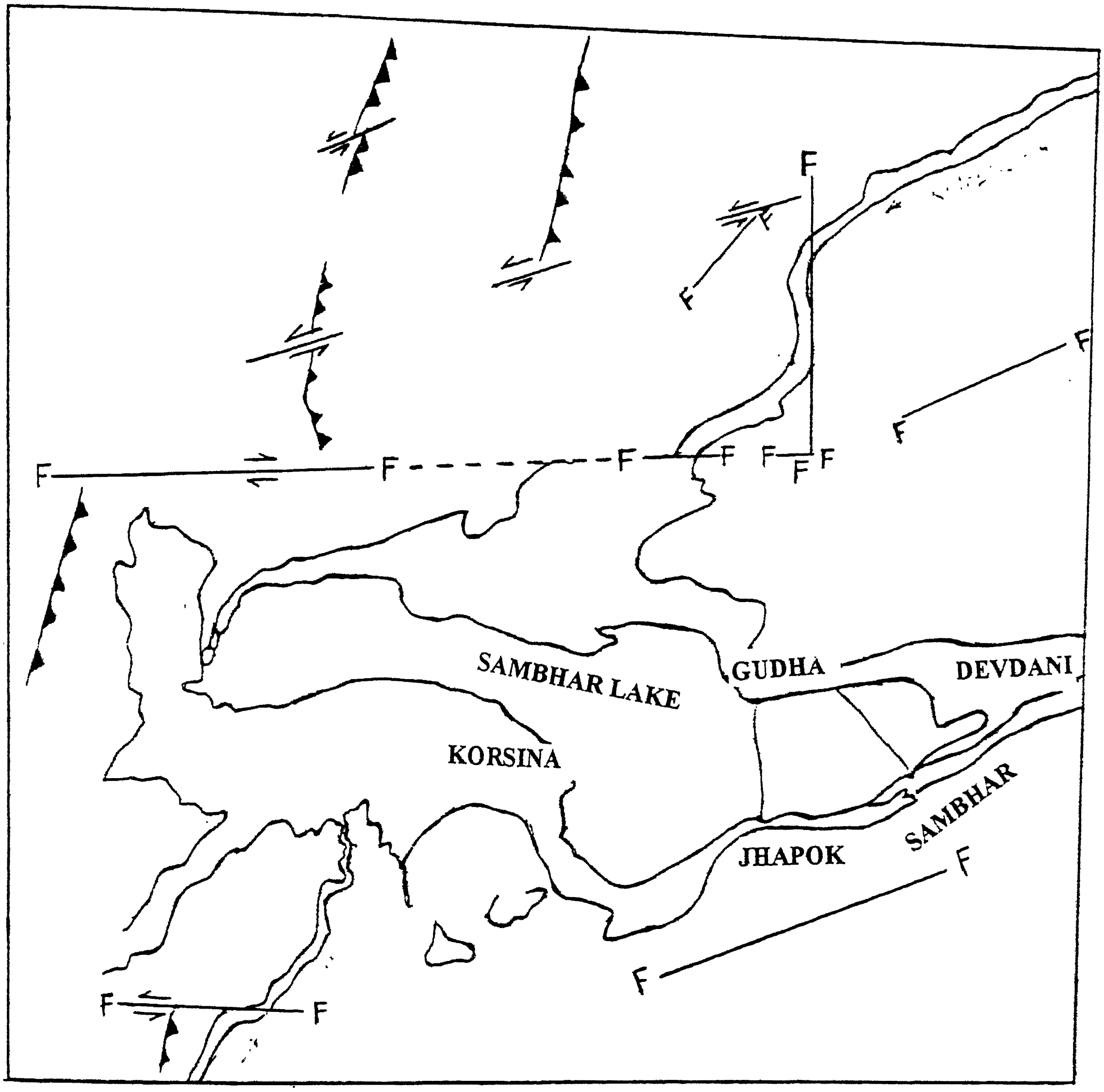


Fig. 3.4 Structural map of the study area prepared from filtered (High Pass Kernel) satellite image of the Sambhar area

One is present towards the west of the mountain range while other three can be demarcated by considering that the E-W elongated Sambhar lake is on the block which is sandwiched between two separate blocks towards its North and South respectively. These three blocks may have been rotating, moving and/or tilting individually. There is a growing debate about the origin of the Sambhar basin as a result of such tectonic activities. From the shifting of the channel of Mendha river it has been inferred that the block towards the north of the lake is tilting in the NW direction, while the block towards the south is also unstable as indicated by the anomalous drainage pattern of the Rupangarh river. The independent movement of these two blocks might have led to the formation of some weak linear zone which eventually developed into Sambhar lake basin. The wind blowing from the gap in the Aravalli has done a great job through deflation of the lose material produced by tectonic activity along this linear zone, finally making a great depression in the sand. Apart from the independent movement of the individual blocks, a number of faults have been reported (Fig. 3.4) in each block. The drainage pattern in the blocks on either side of the lake manifests a number of faults. The broken hills of the Aravalli range also indicate 'faulting activity. The upliftment of the Aravalli along normal faults (Plate 3.15) at places is also noticed in the field. There are more than one generation fault reported in each block which is finally producing a superimposed pattern.

3.5. SUMMARY

The chapter has emphasized the potential of remote sensing techniques for landform mapping and interpretation of various geomorphic processes operating in the region. On regional scale, the aeolian process are indeed dominating as reflected by

Plate 3.15 Ground photograph showing a part of an entrenched stream with its thick soil embankment suggesting upliftment of Aravalli hill at the background

widespread sand dunees, scanty vegitation and other related landforms. The fluvial action is limited spatially as well as temporally. Most commonly small scale alluvial fans have developed on the foot slope of the Aravally hills and a number of dry channels can be seen in the Sambhar lake catchment which are activated only during the moonsoon period that too for a very small time span. The lacustrine processes and their products are governed extensively by aeolian and fluvial processes and their products are governed extensively by aeolian and fluvial process in the region, and of course the climatic conditions. Due to very shallow, but areally extesive, nature of lake, typical lacustrine landforms such as shoreline features, terraces, etc. have not developed. More appropriately, the sambhar lake can be classified as a "wetland" a thin sheet of water is surrounded by swamps. The easternmost rocks and sediments of the lake form the focus of the present study and their analysis is treated in next chapter.

CHAPTER 4

SEDIMENTOLOGY AND ROCK-SEDIMENT MINERALOGY

4.1 INTRODUCTION

A number of studies have been carried out till date to describe the physicochemical evolution of the Sambhar lake. Various workers have adopted different techniques to explore the possible source of the salt in Sambhar lake. Geochemical and isotopic study conducted by Yadav (1995), radiocarbon determinations of the lacustrine deposits of Sambhar by Singh *et al.*(1972), and the geochemical study by Godebole (1952) are some of them. The detailed geomorphological study of the Sambhar lake and the surroundings (see chapter 3) reveals that the source of the Sambhar lake sediments are the exposed Aravalli rocks and the thick aeolian and alluvial plain surrounding the lake. The major geomorphologic agents transporting the sediments to the lake bed are the rivers flowing into the lake and the wind blowing through the gap in the Aravalli. Prior to their rest on the lake bed, the sediments undergo a series of physical and chemical weathering action which are a function of climate, types of weathering agents and neotectonic activity of the area.

Keeping in view the conflicting theories regarding the evolution of Sambhar lake brine, the present study focuses on mineralogical study of the source rock and fluvio-lacustrine sediments of the area to understand the sediment water interaction phenomenon.

4.2. INVESTIGATION PROCEDURE

Keeping the objectives in mind, the rock and sediment samples were collected from various locations (see Fig. 1.1) in the study area. The fresh rocks as well as the weathered part of it were detached from the exposed Aravalli system and then hammered into small rectangular shape for safe carrying and proper utilisation in the laboratory. The lake and river sediments were sampled from different depths through augering at each location (see Fig. 1.1), and were immediately packed in polythene bags to avoid contamination. Then, the samples were labeled on the spot for proper identification in the laboratory. The analysis of source rock samples mainly involved microscopic identification of rock type and the alteration products of the constituent minerals. The results obtained were confirmed through XRD analysis of the powdered rock samples. The sediments were subjected to grain size analysis through dry sieving and clay mineralogical analysis through XRD.

4.3 MINERAL ANALYSIS OF THE ROCK SAMPLES

4.3.1 Methodology

Both the megascopic and microscopic identification of rock were carried out. The thin section of the rock samples were prepared and studied under *LEITZ, LABORLUX II POLS* microscope under different magnifications. The optical properties like colour, shape, cleavage pattern, extinction angle, twinning and interference colours were studied in order to identify the mineral constituents of the rock and their alteration product.

4.3.2 Results and interpretation

The physical observation of the rock samples revealed a variety of features manifesting weathering phenomenon. The schistose rock exposed on the lake bed is severely affected by salt weathering so much so that near Jhapok, fragments of orthoclase and mica are coming off from the rock mass and ready for further action, and pyrite are deposited in the form of small yellow colour tints on the surface of the rock. The red, brown and yellow hues to the surface of all rock samples from nearby hills suggest retention of iron in the ferric state. This impressions on the rock surface needs further explanation, and for which the microscopic study was carried out.

Thin sections of the rocks from the R1 and R2 exposures (see Fig 1.1) shows that these are chiefly composed of quartz, feldspars and mica in different proportions. Samples from R1 has low mica content while the rock from R2 has abundant mica forming layers in between quartzo-feldspathic layer (Plate 4.1a and 4.1b) suggesting the rock as quartzoschist. Sericitisation along feldspar-mica interface is observed under microscope (Plate 4.2). Feldspars are mainly orthoclases of microcline and low albite type as suggested by their cross hatch and albite twinning respectively under microscope (Plate 4.3). The XRD analysis of these rock samples reveals that the alteration product is largely illite with mica-montmorillonite mixed layered clays.

The alteration phenomenon and the characteristic alteration product i,e. illite present in the rock samples from the exposed Aravalli hills suggest that topography and

Plate 4.1 (a and b) Photomicrograph showing the pressence of mica in the rock(450X, crossed nicol)

Plate 4.2 (a and b) Sericitisation along the feldspar edge
(450X, crossed nicol)

late 4.3 Plagioclase feldspar (Albite) showing twinning
(450X, crossed nicol)

Plate 4.4 Doleritic rock showing plagioclase laths surrounded by chloritised augite(450X, crossed nicol)

climate are the key factors controlling the rate of chemical weathering and the nature of weathering products. Even though the Aravallis have steep slopes, the fractures and ruptures in the rock mass cause sufficient infiltration of rain water. However, as the climate of this area is typically semi-arid and the evaporation exceeds precipitation to certain extent, the water penetrating the rock returns to the surface during the ensuing long dry-spell and ultimately and is ultimately evaporated. As a result, the soluble constituents i,e Na^+, K^+, etc. are not removed to their best extent and thus reactions are slowed down accordingly. This results in abundant partly altered parent minerals such as feldspars and micas along with the formation of calcretes (Sunderam and Pareek, 1994).

Doleritic rocks were observed at R3 exposure (see Fig. 1.1) and thin section of this doleritic rock under microscope (Plate 4.4) shows feldspar laths surrounded by altered augite (chloritised) ground mass. It indicates that the mineral alteration taking place here is may be due to the oxidised environment brought about by high temperature climate, and can be shown as

$$\text{Augite} + H^+ + O_2 + H_2O = \text{Chlorite} + \text{Goethite} + Ca^{2+} + H^+$$

The plagioclases present in this rock are mainly An_{37} to An_{60} as calculated from their extinction angle. Presence of some high Na-plagioclase (albite) is also reflected by albite twinning of thin lamellae type with low extinction angle.

The weathered quartzite rock sample from lake bed shows a large deposition of iron oxide along the cracks of the rock (Plate 4.5). The presence of pyrite (FeS_2) in the form of small yellow colour tints on the surface of the rocks as identified in hand specimen

Plate 4.5 Quartzites at lake bed showing deposits of iron oxides in them(450X, crossed nicol)

collected from lake bed, and the presence of Na_2CO_3 in the lake brine suggest that the probable reaction taking place in the deposition of iron oxide is

$$2FeS_2 + O_2 + H_2O + Na_2CO_3 = Na_2SO_4 + Fe_2O_3.nH_2O + CO_2 + 4S$$

Here, the photosynthetical algae present in the environment is playing a major role by removing the CO_2 from the system and thus putting the reaction in the forward direction.

4.4 GRAIN SIZE ANALYSIS OF SEDIMENTS

4.4.1 Methodology

The sediments sampled in the field were analysed for grain size distribution through dry sieving. Prior to sieving the samples were digested in dilute HCl acid for the liberation of sand grains, and then, were washed in distilled water and properly dried. 100 gms of these samples were then sieved for 20 minutes using mechanical shaker. For size analysis of these friable sands, a $\frac{1}{2}\phi$ (phi) sieve interval was used to obtain a reasonable accuracy. Individual size fraction of each samples thus obtained were weighed and noted in a tabular form for the required statistical calculation.

4.4.2 Results and discussion

Using Folk's formula, the various size parameters, such as mean grain size and standard deviation have been calculated. The average values of statistical parameters of 12 samples are listed in table 4.1.

Table 4.1: Statistical grain size parameters of different samples (J = Jhapok, M = Mendha)

SAMPLE No.	MEAN SIZE	STD DEV.
J1	3.0361	0.6307
J2	2.6953	0.6703
J3	2.7674	0.5985
J4	2.8937	0.6991
J5	2.7656	0.6265
J6	2.6986	0.6575
J7	2.5426	0.6688
J8	2.6702	0.6374
M1	3.8352	0.2647
M2	3.8679	0.2851
M3	3.8916	0.3366
M4	3.7169	0.3299
M5	3.6890	0.4058

The bivariate plots between mean size and standard deviation were generated (Fig. 4.1) for the obtained data listed in table 4.1. Friedman (1967) has considered that plotting mean size Vs standard deviation provides an effective discrimination between river, dune and beach sands. This plot reveals that the samples from Mendha river channel and those from lake bed are forming two distinct clusters. Since the lake has no significant tidal or current action, this difference in grain size characteristics between the lake sediments and those of the river (Mendha) feeding it is either due to the different source of sediments or, largely, due to the chemical reaction of the same sediments in the lake water. The later one seems more likely case here in this lake environment, as the finer particles after taking rest in the lake shows progressively more "geochemical activity".

Size frequency curves (Fig. 4.2 a and b) have also been analysed for identifying sedimentary processes and depositional environments, as suggested by Visher (1969). The

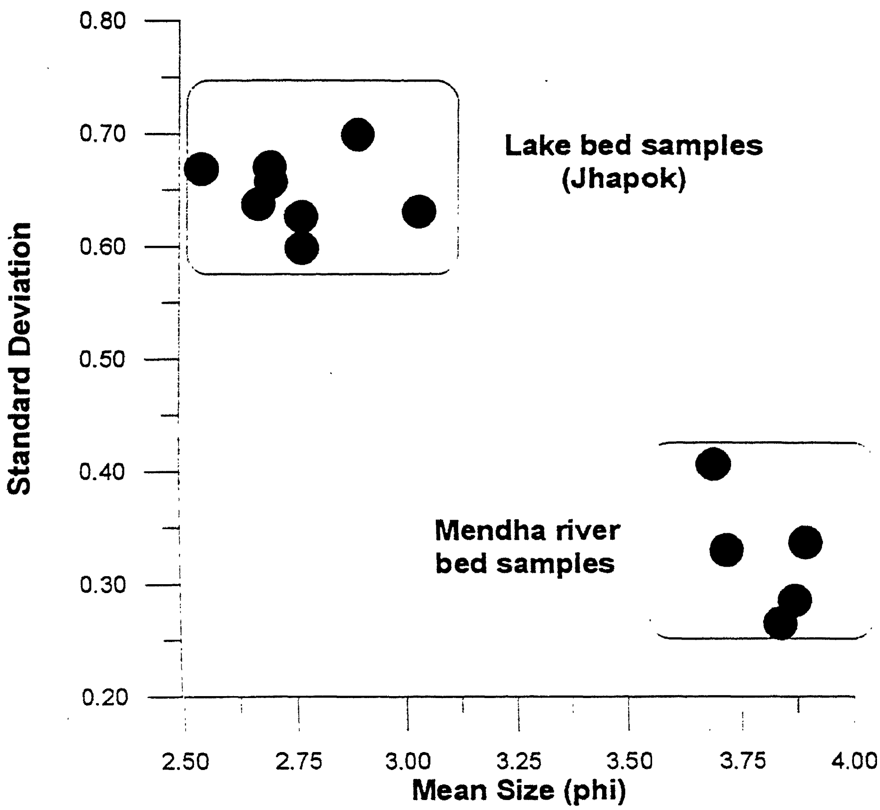


Fig. 4.8 BIVARIATE PLOT OF SEDIMENT SAMPLES FROM MENDHA AND JHAPOK

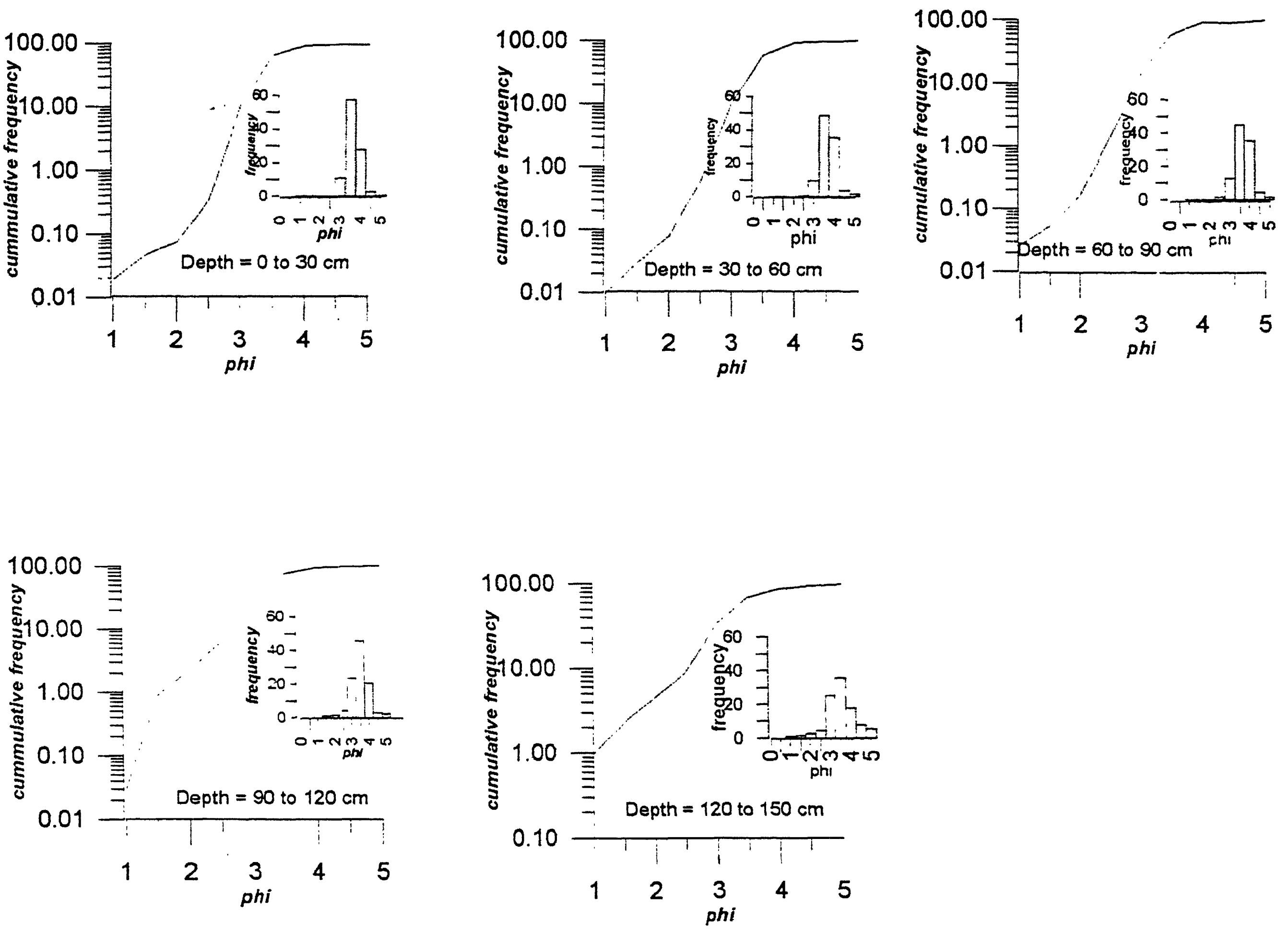


Fig. 4.2 (a) Log-normal and frequency curves of the sediment samples from the Mendha river channel sediments

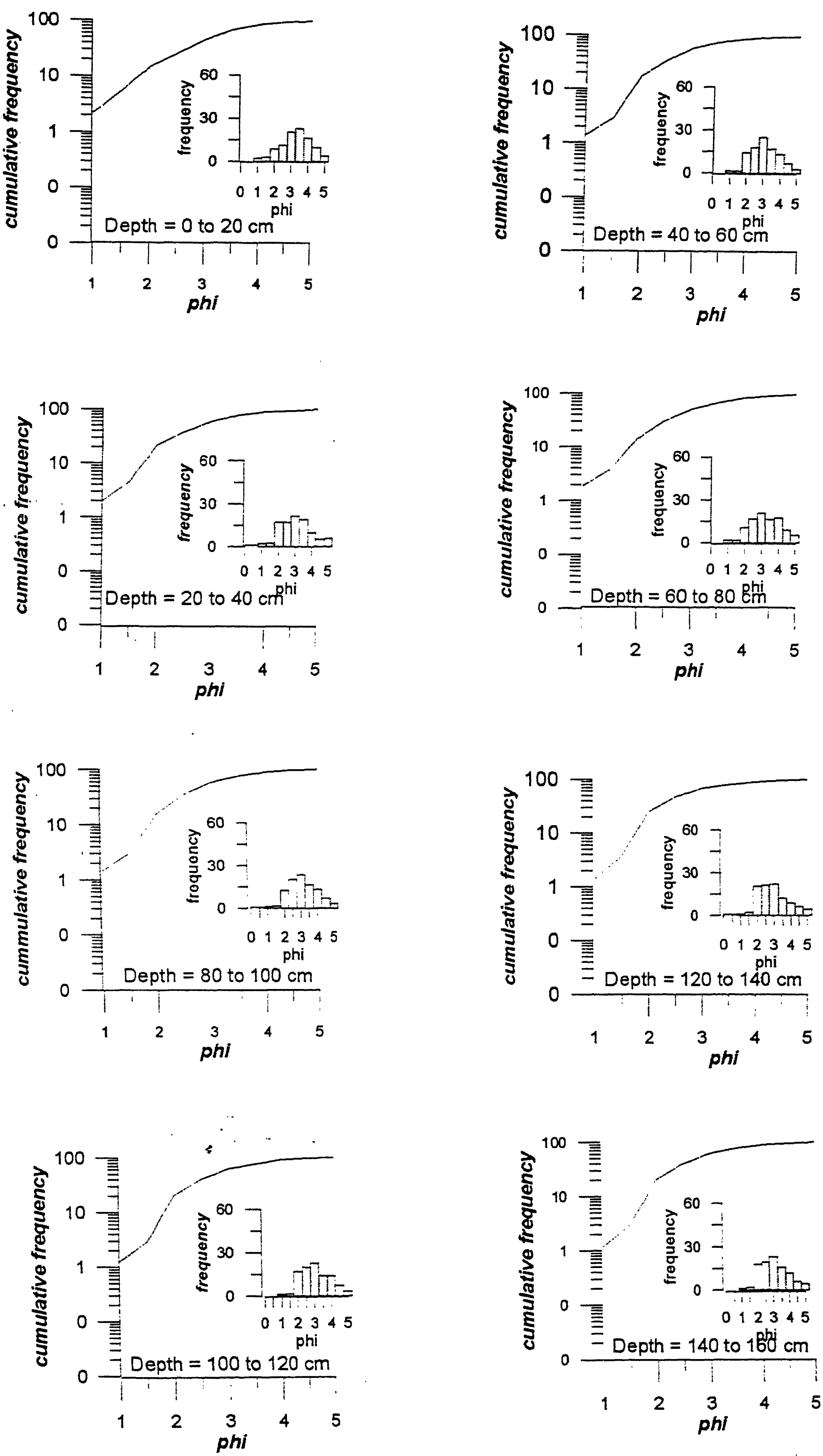


Fig. 4.2 (b)Log-normal and frequency curves of the sediment samples from the lake bed at Jhapok

entire grain size distribution of all the collected sediments consists of several log-normal poulations as inferred from the plots between phi, and cumulative frequency taken in logarithm scale. From the shape of the individual curves it is observed that the top three samples from Mendha river channel sediments are differing from those present below it. It suggest that the top layer of the sediment up to 90 cm depth are wind transported, and the sediments present below to it are river transported. Hence, the river subsequently flowing into the lake during the monsoon must be carrying huge amount of wind contributed sands.

In the lake, the topmost layer (Fig. 4.2 b) has a different expression from the underlying sediments. When tried to correlate with the sediments of the Mendha river channel, it was found that this topmost layer of the lake sediments is matching to certain extent with those collected at 120-150 cm depth from the river channel, except the subpopulations representing transportation through saltation are lacking in this lake sediment. However, all these plots representing lake sediments confirm that the large fraction of them were carried into the lake through suspension.

The bar diagrams (Fig. 4.2 a and b) obtained by plotting phi Vs frequency also confirm the above discussion. In the Mendha channel sediments the wind derived top layers up to a depth of 90 cm mainly comprise of grains of the size range of 3.5 to 4.5 ϕ, while with depth the larger size fractions are dominating. However, all these plots for the Mendha channel samples are leptokurtic and shows normal distribution. In contrast, the

lake sediments are of mixed population as indicated by their higher values of standard deviation with kurtosis and skewness being zero.

4.5 CLAY MINERAL ANALYSIS OF SEDIMENTS USING XRD METHOD

X-Ray Diffraction (XRD) method is particularly useful for analysis of fine grained material which is difficult to study by other means. XRD provides the most efficient method for the determination of clay minerals in sediments, which may yield important information about provenance, weathering processes and depositional environment.

4.4.1 Methodology

The samples brought from the field were pretreated with 35% hydrogen peroxide to remove organic matter, cementing materials, etc. After this the samples were sieved to obtain the necessary size fraction between 270 and 325 A.S.T.M. sieve range for greater accuracy. The next step was to present the sample to the X-ray beam for which smear mount were prepared with distilled water on to a glass slide. This type of mount produces a partially oriented sample (Tucker, 1991). The smear mount is then inserted into the X-ray diffractometer *ISO-DEBYEFLEX 1002* model of *RICH SEIFERT & Co.* at 20 MA/30 KV using Cr-K_α radiation with monochromater.

After the X-Ray chart of the individual sample between 6^0 and 50^0 of 2θ value was obtained, peaks were identified in terms of 2θ angle and converted to lattice spacing using conversion chart of 2θ to angstrong (D-spacing). The problem creating ragged and overlapping peaks were deconvoluted using the method suggested by Tucker (1991).

Then the D-spacing of each peak were matched with the table of consecutive lattice spacing for the common clays provided by Joint Committee on Powdered Diffraction Standard (JCPDS).

As the intensity of the diffraction pattern of a mineral in a mixture is proportional to its concentration, it is possible to make rough estimation of the relative proportion of the minerals in a sample by measuring their relative peak heights or areas (Tucker, 1991). In the present case, the peak area of the individual minerals were calculated by multiplying the peak height above background by their width at half peak height. However, in case of overlapping peaks, which make the area calculation difficult, height was used as a measure of relative proportion. The relative intensities of the minerals present were calculated by taking the intensity of quartz present in that particular sample as the standard. While in case of correlating the quartz quantity of different samples, further, the highest quartz peak among all the sample was taken as unity and accordingly the intensity of quartz present in other samples was normalised. Then, the peaks representing other minerals in the samples were renormalised, and their proportion in samples collected depth wise were graphically represented.

4.4.2 Results and interpretation

The XRD analysis (fig. 4.3) of sediments from the Mendha river bed and the soil sample near the rock exposure R1 (see Fig 1.1) shows the presence of illite and along with quartz and feldspar. The intensity of the illite peaks in Mendha river bed sediments indicate that the illite component in the sediment is not varying with depth. This is because

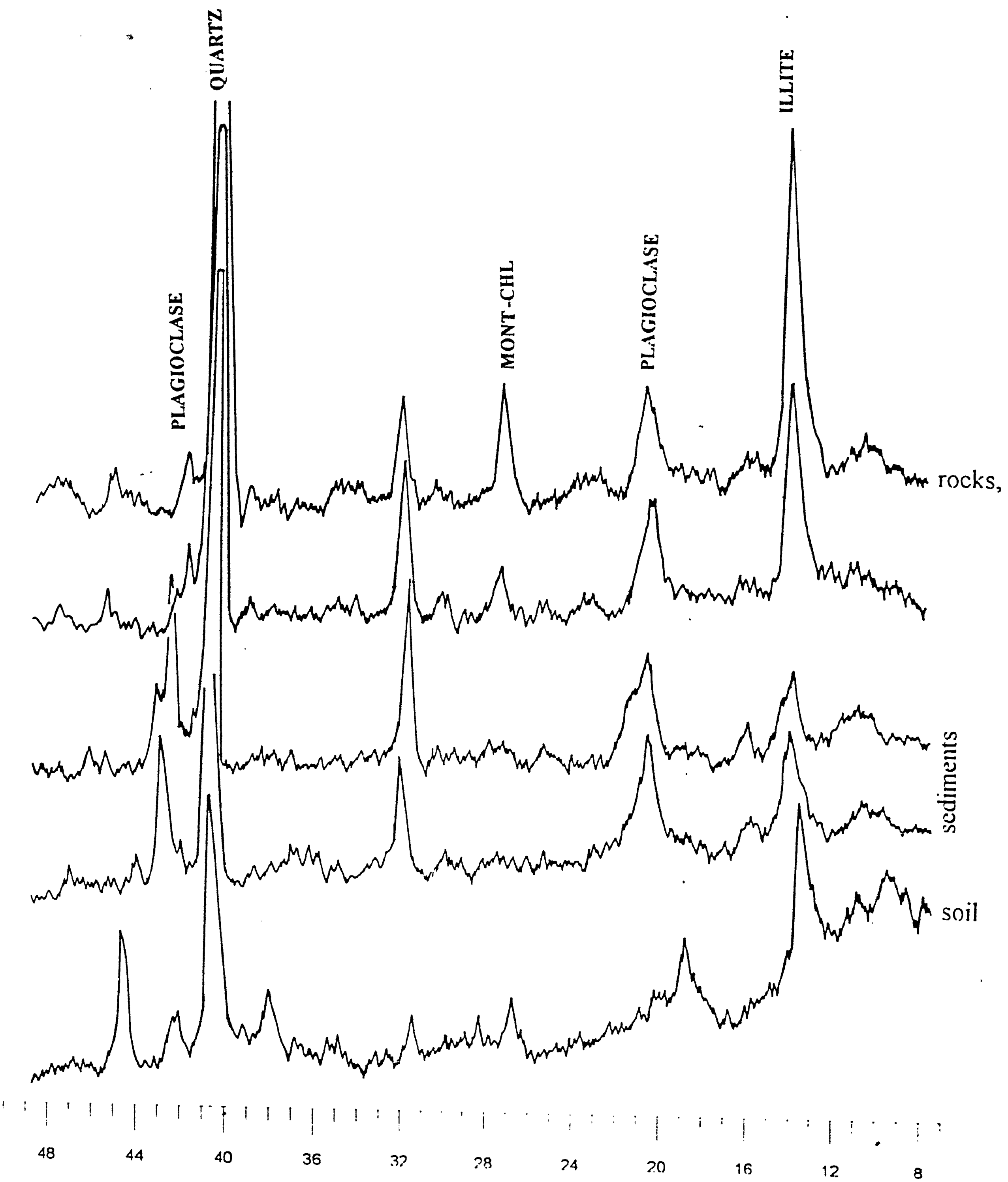


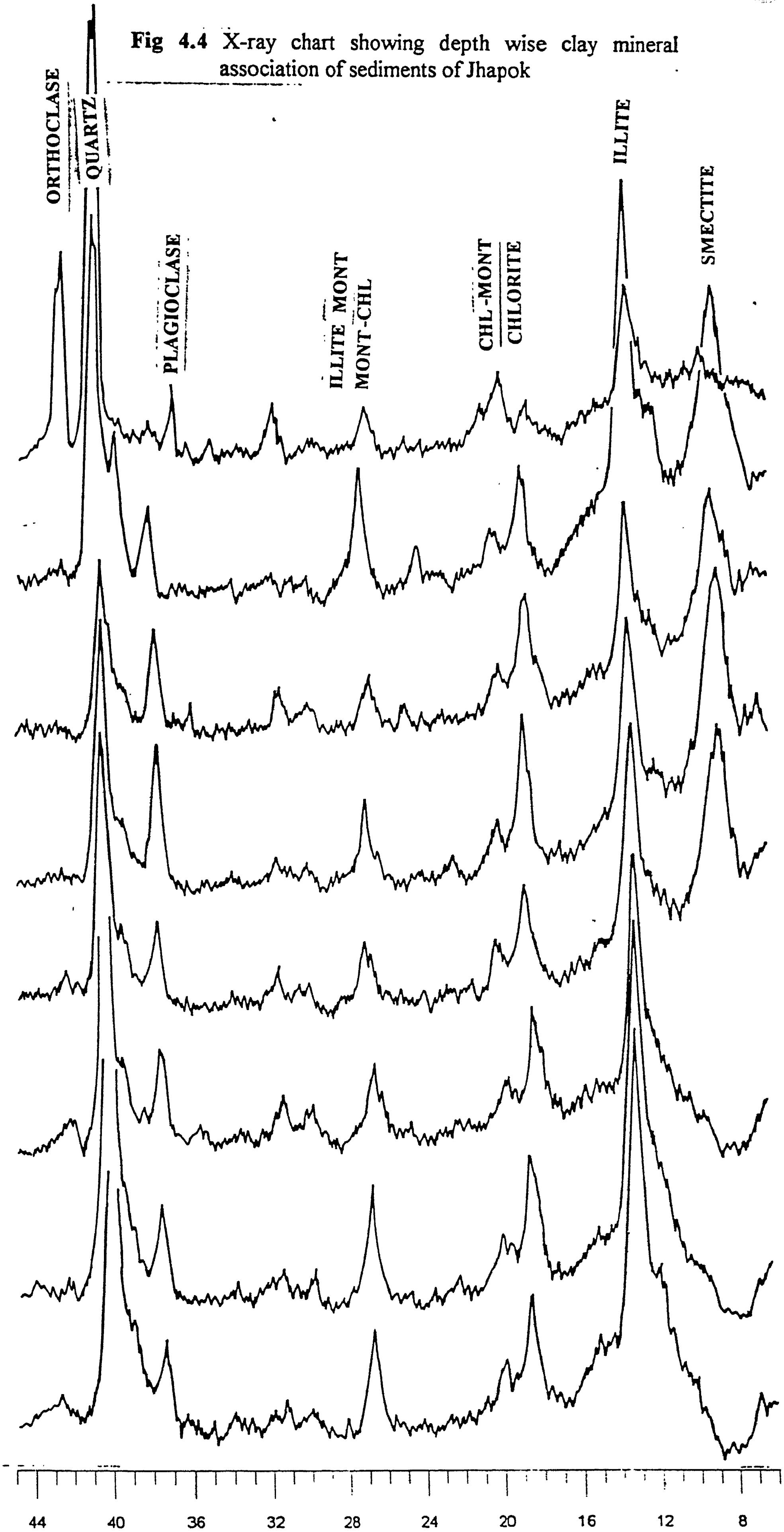
Fig. 4.3 X-ray chart of rocks, sediments and soil collected in the field

the flat, low-lying, sandy river bed experiences runoff only during the monsoon; the infiltration of water after rain is at a maximum, and the subsurface drainage might be sluggish so that the soluble products released by hydrolysis reactions persist in the environmental water, thus inhibiting the further breakdown of the parent minerals. As the parent sediments are relatively rich in alkalis and alkaline earths and as the water from the nearby hills are suggested to be charged with such ions the environment become distinctly alkaline. The water table is at a shallow depth (about 5m) as reported in open wells, and at some place above ground level forming brackish swamps, thus creating a strongly reducing environment. The ground water data of Yadav (1995) from various locations also indicate brackish environment.

The XRD of lake sediment samples taken up to a depth of 1.6 m by augering near Jhapok (J in location map) shows that clay minerals present are mainly illite, chlorite, smectite, and their mixed layered clays. The XRD pattern of these sediments is shown depth wise in Fig. 4.4 and their relative proportion is represented graphically in Fig. 4.5. A careful scrutiny of Figs. 4.4 and 4.5 reveals that feldspar is absent at depths below 20 cm. Smectite appears at a depth of 20 cm. Also the mixed layer clay is changing from chlorite-montmorillonite type to montmorillonite-chlorite type indicating the increase in smectite proportion in the mixed layered clay after a depth of 20 cm. At a depth range of 80 to 100 cm, the mixed layered clays type is appearing as mica-smectite type. Below a depth of 100 cm smectite is completely absent from the scene.

In contrast to the above pattern the XRD pattern of sediments from the lake bed at Gudha (Fig. 4.6) shows some kind of alternate zones. In the top 25 cm layer illite,

Fig 4.4 X-ray chart showing depth wise clay mineral association of sediments of Jhapok



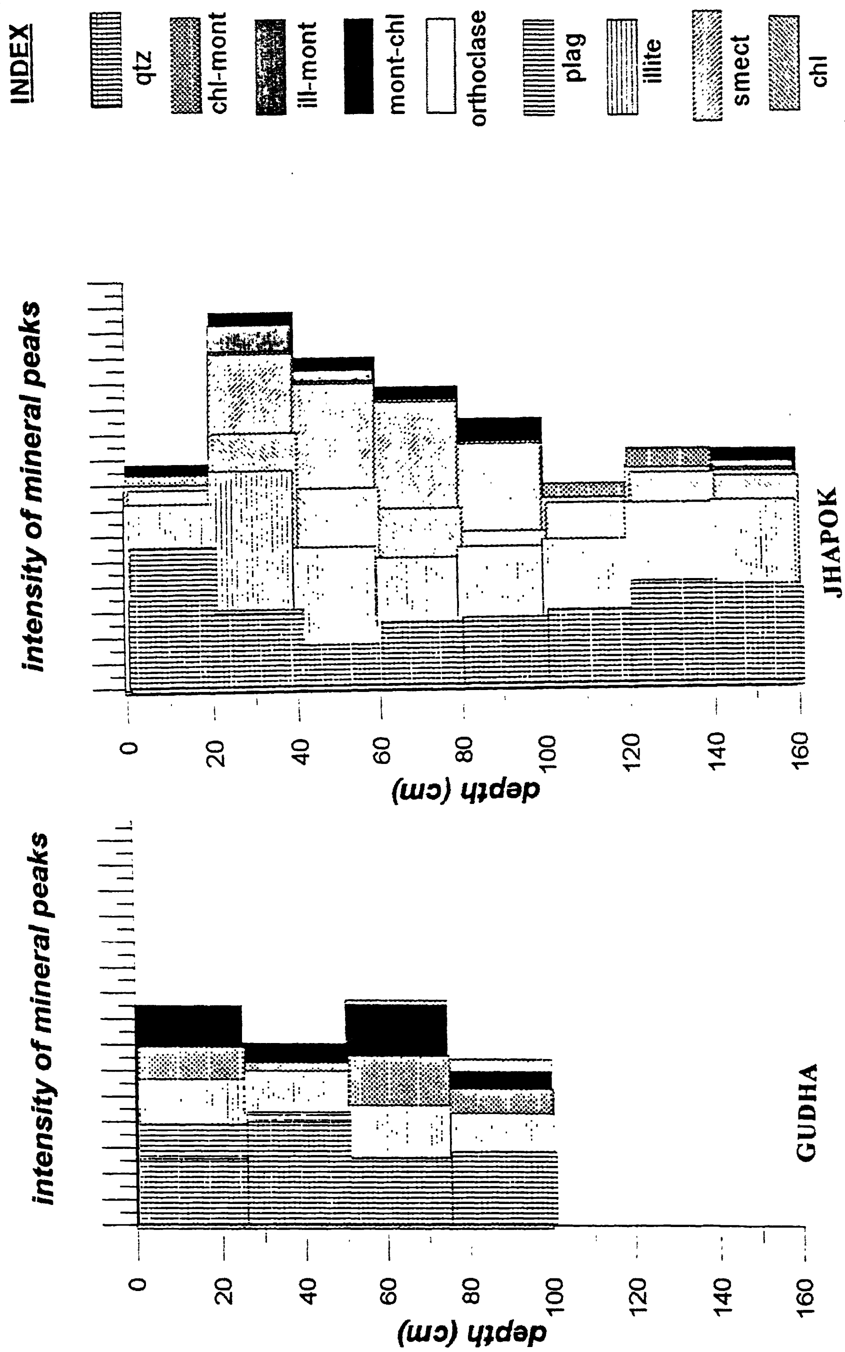


Fig 4.5 Block diagram showing depth wise variation in concentration of different mineral

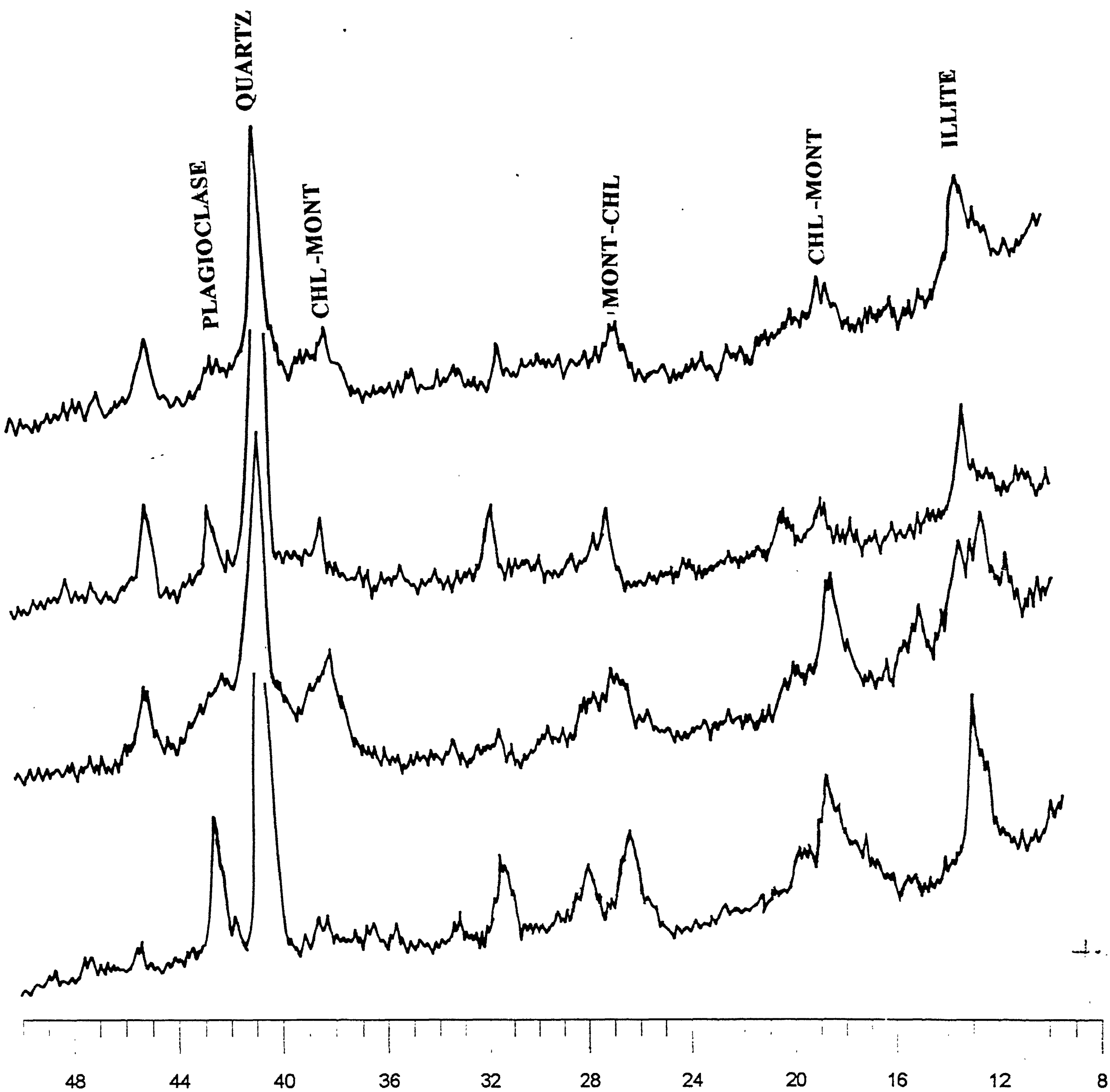


Fig 4.6 X-ray chart showing depth wise clay mineral association of sediments of Gudha

chlorite-montmorillonite are present along with detrital quartz and feldspar. In the next 25 cm depth the increase in the quartz content may be due to the precipitation of authigenic quartz. The simultaneous decrease in concentration of chlorite-montmorillonite and montmorillonite-chlorite mixed layer clay suggest that this layer has developed a low pH zone probably due to high organic activity. Thus the silica dissolved out from the top and bottom layer (higher pH zone) is precipitating here. The third layer of the depth range of 50 to 75 cm is quite identical to the topmost layer (Fig. 4.5 and 4.6). The bottom-most layer again shows deposition of quartz and decrease in the quantity of mixed layered clay.

The clay mineralogy of various section at Jhapok and Gudha site suggest a series of mineralogical transformations. The section at Jhapok being deeper shows that complete cycles on the basis of which two major zones of clay mineral assemblages can be recognised with a transitional layer in-between. At Gudha, only a part of the cycle is apparent partly because of shallow section and partly because of its location with respect to the lake. The description and details of the zones of clay mineral assemblages presented next.

ZONE 1 **(0 - 80 cm)**

- Quartz, orthoclase and plagioclase present in the topmost layer (0 to 20 cm) is considered to be transported. As discussed previously, illite and chlorite are forming in the source rocks and sediments outside the lake bed as alteration product, so their presence in this topmost layer is suggested to be detrital in nature. It is difficult to find out whether the chlorite-illite mixed layered clay present in this layer is detrital or

authigenic. However, its origin due to leaching of pre-existing chlorite and mica can not be ruled out.

- The decrease in plagioclase proportion and the absence of orthoclase in the second layer (20 to 40 cm) suggest that the H^+ from the lake water is replacing K^+ present in the crystal structure of these minerals and thus forcing them to go into solution. The increase in the illite proportion is the result of dissolution of feldspar, and the shifting of illite peak in XRD pattern is probably due to the absorption of K^+ in it's structure. The chemical reactions suggested to be taking place is-

$$\text{Feldspar} + H^+ = HAlSi_3O_8 + K^+$$

$$\text{degraded silicate (illite)} + \text{cations } (K^+) + HCO^{3-} + SiO_2 = \text{cation-Al-silicate (illite)} + CO_2 + H_2O$$

- The appearance of montmorillonite (smectite) in the second layer is due to the reaction of feldspar and ferromagnesian minerals in this water logged alkaline soil. The conversion of mixed layered chlorite-montmorillonite type to montmorillonite-chlorite type is obvious as smectite is precipitating. The decrease in quartz content and the removal of feldspar suggest the following reactions are taking place.

$$SiO_2 + 2H_2O = H_4SiO_4$$

$$\text{Feldspar} + 6H^+ + 2H_4SiO_4 \xrightarrow{water\log gedalk.soil} \text{Smectite} + 4H_2O + Na^+ + Ca^+$$

- The above trend is following into the third layer (40 to 60 cm) in an intense way. Here complete removal of feldspars is indicated by the absence of their peaks in the X-Ray chart. The quartz is going into the solution as in the previous case. The increase in the

concentration of smectite in comparison to the above layer is taking place for the same reasons. Chlorite concentration is increasing probably due to the leaching of illite and mica.

- The transitional layer (80 to 100 cm) is designated so as the trend of the layers bellow is completely different from those above. Probably in this layer lots of organic (algal) activity taking place and thus the Eh value is sharply decreasing making montmorillonite equilibrium with the system.

ZONE 2 **(100 - 160 cm)**

This vertical zone below 100 cm depth shows a completely different pattern from the zone lying above it. Disappearance of smectite, slow increase in the illite content and precipitation of authigenic quartz are the major events noticed from the XRD pattern of sediments from this depth zone.

- The first layer (100 to 120 cm) of this zone is experienced by the dissolution of smectite and chlorite as the high pH produced at this depth due to bacterial reduction of sulfate and possibly base exchange causing disequilibrium of clay minerals with the environment. The simultaneous precipitation of quartz and illite is obvious as the solution is getting saturated with respect to these minerals.

- The mineralogical variation in the second layer(120 to 140 cm) of zone 2 suggest that due to the precipitation of authigenic quartz in the low pH region, the pH of the sediment water is increasing. This phenomenon is schematically shown in Fig. 4.6. With increasing pH montmorillonite is completely replaced by illite as follows :

$$\text{Smectite} + Al^{3+} + K^{+} \rightarrow \text{Illite} + Si^{4+}$$

Chlorite is increasing at the expense of illite and hence changing the type of the mixed layered clay. The reaction can be shown as:

$$\text{Illite} + \text{Montmorillonite-Chlorite} + Fe^{2+} \rightarrow \text{Chlorite} + \text{Illite-Montmorillonite}$$

4.6 SUMMARY

From all above observation it can be summarised that though the rocks and sediments are undergoing chemical weathering, but their soluble products are not removed to their best extent by the water, and subsequently the removed soluble constituents are reprecipitating on the surface of the rocks and sediments during the dry spell.

Wind is a dominant agent responsible for most of the erosion and sediment transport work. Thus the loose products of the weathering and the reprecipitated soluble products are mainly transported to the lake bed by wind. The fluvial transport process is dominant particularly during the monsoon. The distinct variations in the size characteristic between the sediments in the lake bed and those in the Mendha river bed is due to the geochemical processes taking place in the lake.

The weathering of sediments in lake bed is completely different from the weathering taking place in the adjacent plain or rock exposures. Inside the lake all kind of redox reactions are taking place at various depth causing mineral concentration as well as mineral transformation. The algae present in the lake water and sediments are governing the ongoing chemical reactions to a large extent.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The work has been focussed at a rather complex geological phenomenon in a hypersaline lacustrine system. The Sambhar lake system, Rajasthan has been studied for its geomorphology, sedimentology, and catchment weathering. A veriety of techniques have been used for the study viz. remote sensing data alaysis coupled with field investigations, sedimentological analysis of river and lake sediments, clay mineralogical analysis of catchment rocks, river and lake sediments and also limited microscopic analysis of rock thin sections. Based on the results of these analyses, a conceptual model for the physical and chemical evolution has been evolved. The details of the model are presented next.

5.1 PHYSICAL EVOLUTION OF THE SAMBHAR LAKE BASIN

The regional geomorphological features have been studied using the satellite remote sensing data. The geomorphological and tectinic features present in the area as observed in the field and on satellite imageries (Chapter 3) suggest the sequence of events that might have led to the formation of the Sambhar lake (Fig. 5.1). The first post-orogeny movement might have caused the disruption in the Aravalli range (Dassarma, 1988) and during this phase, the Block B was shifted towards west along two strike slip faults demarcating its boundary in the North and South respectively. Its continuation in the east could not be ascertained as the satellite data of this area was not available for the present

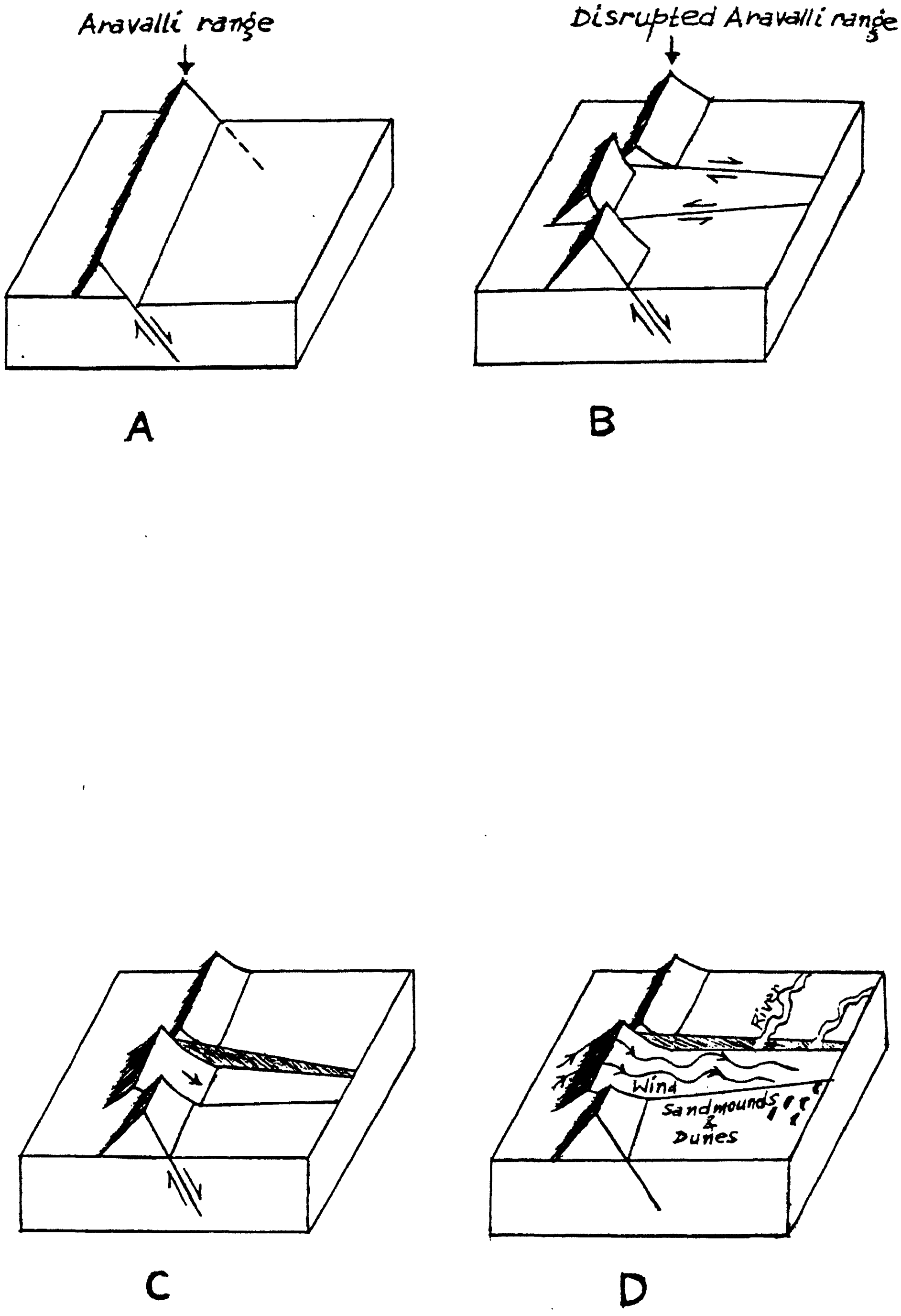


Fig. 5.1 Tectonic model showing differnt stages of Sambhar lake basin evolution

study. The truncated hills, bending and rupturing of Aravalli hills (plate B.1 & fig. 3.5) in this area supports this interpretation. After this, the post orogeny movement during Plio-Pliestocene period (Sen & Sen, 1983) might have caused the upliftment of the blocks, on either side of Block B, along reactivated strike slip faults. This might have ripped open the linear depression forming the Sambhar lake.

Sambhar lake, a quaternary sedimentation basin as described by Roy & Sen (1983), has probably undergone impulsive movements as the presence of faults (Fig. 3.5) in block A suggest. However, this quaternary sedimenatary basin was probably getting the sediments from the river flowing along the E-W trending lineaments (Fig. 3.4). Probably due to filling up of this basin or due to some tectonic movements in the upstream reaches, the river channels later changed their course and left their impression in the form of paleochannels.

Further, the basin has undergone extensive wind deflation. The high wind flowing from the west along the gap in the Aravallis initiated the deflation process excavating a hollow in this quaternary sand. The presence of huge sand dunes and sand mounds along the eastern periphery of the lake supports this intrpretation. The wind action which followed can be described using a geographical model proposed by Greelet & Iversen (1987). According to this model, lee waves often form where mountain ranges are located upwind from flat plains. When air flows over the crest of this range of mountains, it must rise in order to do so. In turn, it descends when traveling over the leeward slope. The momentum gained by the air as it travels down, the slope carries it past an equilibrium

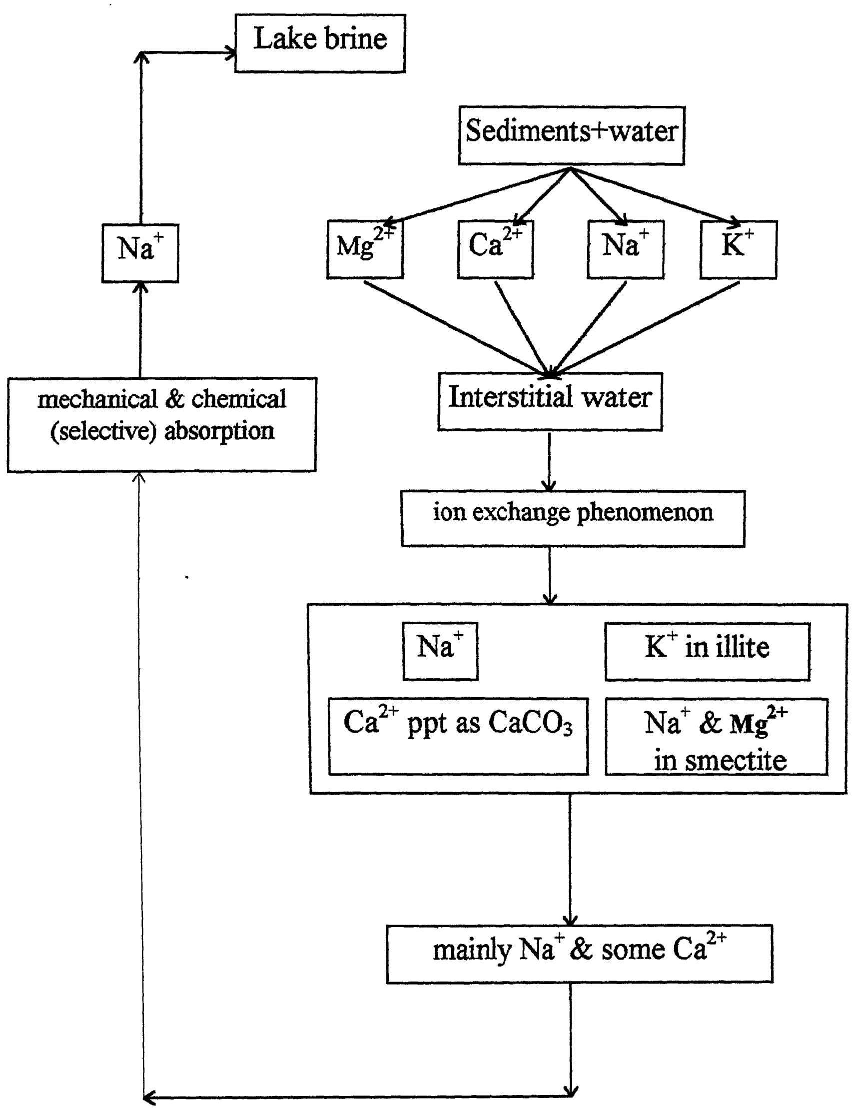
condition, forcing it to 'bounce' back up again. The momentum gained the upward motion again carries it past an equilibrium condition and the air starts downward a second time. The standing wave pattern thus formed can exist for several oscillations as seen in Fig. 5.1D. As a result, this wind blows out the soft materials i.e. sand, if any, present on the surface towards the lee side. The present-day Sambhar lake is therefore an outcome of tectonic and extensine aeolian activity in the region.

5.2 GEOCHEMICAL EVOLUTION OF SAMBHAR BRINE

The available data on the brine chemistry of Sambhar and the sediment-water interaction phenomenon presented in this study (Chapter 4) provides valuable insight into the chemical evolution of the Sambhar lake. The product of catchment weathering, together with a certain amount of unweathered rock material, is carried by wind and river into the Sambhar lake. During transportation, the rock and mineral particle largely undergo mechanical weathering, and little chemical weathering of silicates takes place to a far greater extent in the lake than on the adjoining plains because large amount of chemically active water is available. All the physiochemical processes occurring in this hypersaline lake environment can be termed as "halmirolysis", and is responsible for the existing Na-Co_3-So_4-Cl type brine in the lake (Bhattacharya et al, 1982; Raymahashay, 1996).

Fig. 5.2 shows the various steps of lake halmirolysis as inferred from sediment mineralogy. When the unaltered detrital sediments comes in contact with lake water,

Fig. 5.2 Schematic diagram showing geochemical evolution of the Sambhar lake brine



halmirolysis starts. As a result, the soluble chemical constituents like Na^+, Mg^{++}, K^+, Ca^{++}, etc. in the sand and silt sized mineral fractions get mobilised but they still remain in the interstitial solution making the environment more alkaline. The already existing detrital clays in sediments i.e. illite and chlorite absorbs these ions to produce new minerals or change into some mixed layered type clays.

The smectite in the sediments is transformed stepwise into chlorite as observed in the case of Jhapak sediments, suggesting increased salinity, as a thumb rule with increasing salinity almost all the clay species become decreased with exchangeable cations. These interstitial solution get enriched with respect to Na^+ and Ca^{2+}, the former being dominant. Due to summer heat or mechanical squeezing the interstitial water moves from deeper horizon either vertically or to some extent laterally (up dip) into higher formations in which the chemical equilibrium may be completely different from that of the underlying sequence.

Here, considering the possibility of the operation of "selective chemical filtering", it can be explained that the passage of interstitial water heavily charged with organic and inorganic solutions and collides, through a porous membrane is likely to cause filtering of large molecules and ions of opposite charges to that of the membrane. In as much as quartz in the sediments carrying no charge, the separation is mechanical, i.e. differential capilarity. As the clays are present to a great extent in the sediments this filtering is also chemical. This is obviously taking place as montmorillonite (smectite) which has strong negative charges is present in the sediment. At first the passage of the negatively charged

ions are mechanically restricted and then the corresponding cations (Ca^{2+}, Mg^{2+}, Na^{+} & K^{+}) get trapped.

In the meantime, calcite precipitates out with evaporation which quantitatively removes Ca^{2+} ions from the sediments solution. The calcite precipitation is well reported by XRD of untreated sediment samples in the lake bed at Jhapak. After the precipitation of calcite no pure Ca-mineral precipitate. However, subsequently Mg-minerals like Mg-smectite precipitate out which is well observed in the near surface (zone 1) zone of Jhapak sediments. In this zone the presence of large quantity of illite strongly suggests that fixation of K^{+} in three layered expansible clay i.e. smectite, is too strong to be exchanged by ordinary cation exchange capacity reaction.

After all these conversion, fixation and transformation processes the final interstitial water which apparently move upward due to overburden or due to evaporation from the final composition either of Mg^{2+}-Na^{+} -SO_4-Cl type or Na-CO_3-SO_4-Cl type, depending upon the Mg^{2+} / carbonate alkalinity. The Sambhar lake brine has been reported to be of Na-Co_3-So_4-Cl type (Bhattacharya et al, 1982; Raymahashay, 1996). The model outlined above therefore still does not explain the presence of SO_4^{-2} and Cl^{-} in the lake brine which further probing of sediments and integrating the detailed water chemistry data into the model.

5.3 SUGGESTIONS FOR FUTURE WORK

Sambhar lake is a complex geological and geochemical system and the work presented in this thesis is still inadequate to explain its evolution completely. The following aspects need further attention to unravel the complexities of this very interesting area :

1. A modified algorithm may be needed to distinguish vegetation in the desert area in the processed satellite data, which in turn would have helped in locating the lineaments. The

2. The sharp difference in reflectance of lake water from different parts of the lake seems very interesting and it must be related to differnce in salinity level, type of algal growth and other biogeochemical parameters which needs further investigation.

3. Laboratory experiment is needed to find out the change in size parameter of the provenance sediments, when put in a solution similar to lake, which suppose to help in justifying the discrimination in bivariate plot.

4. The pore fluid chemistry of lake sediment samples may provide vital clues to the geocjemical cycle responsible for the origin of hypersalinity in the lake.

BIBLIOGRAPHY

Anhert, F. (1970) Functional relationship between denudation, releif and uplift in large mid-latitude drainage basins, Am. Jour. Sci. v. 268, No.3., pp.253-263.

Bhattacharya, B. N., Gupta, S.K., Rishi, B.P., Mitra, A. K. & Kashyap, V. K. (1975), Seasonal Variation in composition of Sambhar lake brine and possible origin of its salinity, Proc. Workshop on the problem of deserts in India, GSI, Jaipur.

Blatt, H., Middleton, G. V. and Murray, R. (1980) Origin of sedimentary rocks, 2nd ed. Englewood Cliffs, NJ: Prentice Hall.

Bloom, A. L. (1969), The surface of the earth, Prentice-Hall, Inc., Englewood Cliffs, New Jersy.

Dassarma, D. C. (1988) Post orogenic deformation of the Pre- Cambrian Crust In North-Eastern Rajasthan, In: Precambrian of the Aravalli Mountain, Rajasthan, India; geol. Soc. India; Bangalore; Memoir 7, pp. 109-120.

Eugster, H.P. & Hardic, L. A., (1978) Saline lakes; In: Lake Chemistry Geology Physics, Spiringer verleg.

Godbole, N. N. (1952), "The salinity of the Sambhar lake", Bull. Nat. Inst. Sci. Ind., 1, 89-93.

Gopal, B. and Sharma, K. P. (1994) Sambhar lake Rajasthan (Ramsar site of India), WWF publication. 37p

Greelet, R. and Iversion, J. D. (1987) Wind as a geological process, Cambridge planetary Sc. series, Cambridge University Press.

Gupta, R. P. (1991), Remote Sensing Geology, Spinger-verlag, Berlin Heidelberg

Jensen, J.R. (1986), Introducing Digital Image Processing, Pretince-Hall, New Jersey.

Lillesand, Thomas M. and Kiefeer, Ralph. W. (1994) Remote Sensing and Image Interpretation, - 3rd ed. John Wiley & Sons.

Mokhopadhya, D. and Dsagupta, S., (1978) Delhi- preDelhi relations near Bandar, Central Rajasthan, Indian Jour. of Earth Sci., v.7, pp.64-75 .

Ray, Terril W. and Murray, Bruce C. (1996), Nonlinear Spectral Mixing in Desert vegetation, Remote Sens. Environ. vol.55 pp.59-64.

Raymahashay, B.C. (1996), Geocemistry for Hydrologists, Allied Publishers Limited.

Rees, C.C. (1968) Introduction to paleolimnology; Development in Sedimentology, Elisevier publishing company.

Roy, A. B. (1988) Stratigraphy and Tectonic framework of The Aravalli Mountain Range; In: Precambrian of Aravalli Mountain, Rajasthan, India; Geol. Soc. Of India, Bangalore; Memoir 7, pp. 3-32.

Roy, A. B. and Das, A. R. (1985) A study of the time relations between movements, Metamorphism and Granite emplacement in the middle Proterozoic Delhi Supergroup Rocks of Rajasthan, Jour. Geol. Soc. India, v. 26 pp. 229-236.

Roy, J. N. and Sen, S. (1983) Post neogen tectonism along the Aravalli range, Rajasthan, India, v24, pp. 229-236.

Sen, D. and Sen, S. (1983) Post neogen tectonis along Aravalli range, Rajasthan, India, Tectono Physics, V. 93, pp. 75-98

Sharma, Ram S.(1988), Pattern of Metamorphism in the Precambrian rocks of the Aravalli mountain, Rajasthan, India; Geol. Soc. of India, Bangalore, Memoire 7, pp. 33-77.

Singh, S. P. (1988) Stratigraphy and Sedimentation pattern in the proterozoic Delhi Supergroup, North western India, In: Pre Cambrian of Aravalli Mountain Rajasthan, India, Geol. Soc.of India, Memoir 7, pp 193-206

Sundaram, R. M. and Pareek, S. (1995) Quaternary facies and paleoenvironment in north and east of Sambhar lake, Rajasthan. Jour. Geol. Soceity of India, v.46, pp. 385-392

Tucker, M. (1991) Techniques in sedimentology, Blackwell Scientific Publications.

Yadav, D.N. (1995) Chemical and isotopic studies in coastal area of the Arabian sea and saline lakes of Rajasthan (India). Unpublished Ph. D. thesis, M. S. University, Baroda.